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Validation of the DELCAP Airport Simulation Model

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Washington, D. C. 20234

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Final Report

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This report documents exercises of the DELCAP airport simulation model performed to validate the outputs of that model. Airport throughput levels were calculated by DELCAP for five runway configurations, with three or four appropriate operating policies chosen for each, and for three different mixes of aircraft types. These estimates from DELCAP agreed well, generally within 6 to 8 percent, with current values provided by the FAA. An attempt at validating DELCAP's delay-figure output, using existing data on scheduled and actual times of aircraft departures and arrivals, is also reported. It proved unsuccessful, because available data are not sufficient to isolate that portion of total delay which DELCAP is designed to measure, i.e. terminal area ATC delay. A collection effort to accumulate the necessary data is formulated. Appendices to the report contain program listing, flowcharts, descriptions of program changes from earlier versions, and user instructions for the model's operation.

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U.S. DEPARTMENT OF COMMERCE, Rogers C.B. Morton, *Secretary*
James A. Baker, III, *Under Secretary*
Dr. Betsy Ancker-Johnson, *Assistant Secretary for Science and Technology*

NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Acting Director*

ABSTRACT

This report documents exercises of the DELCAP airport simulation model performed to validate the outputs (delay and capacity) of that model. Airport throughput levels were calculated by DELCAP for five runway configurations, with three or four appropriate operating policies chosen for each, and for three different mixes of aircraft types. These estimates from DELCAP agreed well, generally within 6 to 8 percent, with current values provided by the FAA. An attempt at validating DELCAP's delay-figure output, using existing data on scheduled and actual times of aricraft departures and arrivals, is also reported. It proved unsuccessful, because available data are not sufficient to isolate that portion of total delay which DELCAP is designed to measure, i.e. terminal area ATC delay. A collection effort to accumulate the necessary data is formulated. Appendices to the report contain program listing, flowcharts, descriptions of program changes from earlier versions, and user instructions for the model's operation.

Key Words: Airport; airport capacity; airport simulation; models; model validation; runway capacity; simulation; validation.

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1. INTRODUCTION

1.1 Background

In 1969 the FAA asked the National Bureau of Standards (NBS) to review its Airport Capacity Handbook, developed by Airborne Instruments Laboratory (AIL) in June 1963, and to evaluate the possibility of reapplying or extending that Handbook's airport capacity model so as to account for new aircraft types and mixes of aircraft types. The documentation proved insufficient to permit reconstructing the AIL model, which in effect had been "lost" during the intervening years. Consequently NBS developed an analytical model, for the simple case of a single runway handling landings only, and documented it in [4] and [7]. See also [8] and [9] for similar results. Subsequently NBS extended the analytical model to dual-use runways and multi-runway configurations, in [5] and [6].

In the process of carrying out the extension, it became evident that the analysis for complex configurations was very difficult, and there was a possibility the analytical expressions would prove intractable. To ensure ability to handle a large range of configurations despite possible difficulties in the analytical modeling, it was decided to develop concurrently a simulation model. The DELCAP model, documented in [1], was the result of this effort. Its design principle, described in the first chapter of that documentation, is the "model as little as you can" philosophy under which only those system elements with direct influence on stipulated output measures are included in the model. This philosophy assumes a well-defined set of applications for which a model is to be designed, and recognizes that the resultant model may thus be unsuited for other applications. Specifically, DELCAP was designed to calculate average maximum throughputs and delays resulting from airport airside operations in a terminal area.

Input parameters which were included in the model, and therefore may be varied, include:

separation rules*,
aircraft type mix,
characteristics of each aircraft type,
traffic levels,
airport runway configuration,
operating policy.

DELCAP was commissioned as a planning tool, and so major criteria in its design were that it be easy to use, have a short computer running time, and be economical enough to encourage its use to answer a variety of "what if" questions concerning airport capacities and airside delays.

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* The non-metric units, nautical miles, knots, feet and pounds, used in this report are those customarily employed in aviation.

The design and development of DELCAP were completed in this first effort, and the documentation was issued in May 1971. However, only illustrative runs designed to demonstrate its versatility and scope were made at that time.

In early 1974 the FAA's Air Traffic Service requested that the DELCAP model be reactivated, some modifications be made in it, and that it be validated for use in their Engineered Performance Standards (EPS) program for calculating target throughput levels at busy airports. This report documents that effort. An interim report [2] described the validation of throughput output from DELCAP; the results reported there have been incorporated in the present document to make it self-contained.

One caveat should be noted at the outset. The validation exercises reported here are aimed at assessing validity of DELCAP for a specific application, that of setting ATC system performance standards. The parameter ranges, configurations, and operating policies involved in the exercises are those to be found in that application. Therefore, although the validity of DELCAP has been established for input values in the ranges required by this one application, validity has not been established for all possible inputs and scenarios. The context of EPS presented a wide range of configurations and operating policies, so that our validation exercises do cover most of today's busy airport scenarios, indicating the model's usefulness in estimating throughputs at these facilities. Still, caution must be exercised if the DELCAP model is to be applied in other contexts, since validity has been established only in the limited sense noted above.

DELCAP is now operating both at NBS on the UNIVAC 1108 computer and on a CDC computer chosen by, and accessible to, the FAA. On both systems it may be operated remotely from a teletype terminal, which allows the analyst to use the model at his desk as "what-if" questions occur. The model has been used as a tool by FAA analysts in establishing EPS's, that is, traffic levels which a facility should be able to handle during busy hours, under a particular configuration and operating policy, with a given mix of aircraft types and a given arrival/departure ratio. Calculations which formerly had to be performed by hand (by FAA analysts) are now done by DELCAP, which, because it is inexpensive, quick and easy to use, can help investigate a wider variety of configurations and operating policies. Runs typically require 15 to 20 seconds to simulate one day's traffic. This speed and flexibility allow the analyst to set performance standards for conditions which occur less frequently as well as for the normal situation, since a large number of alternatives can easily be tried.

1.2 The Validation Process

Once a mathematical model has reached operational status, there is a natural temptation to put it directly to practical use, skipping over any substantial effort to verify that the model does in fact do what it was designed to do. Such an omission, however, courts disaster, since a model which has not been exercised on a variety of data (and had its outputs compared with what is actually observed in the situation being modeled) may contain unsuspected anomalies likely to exhibit themselves at embarrassing moments or (even worse) to remain undetected. To guard responsibly against this, it is necessary to subject the model to a pre-use validation and preliminary sensitivity analysis.

Validation involves two types of analysis. The first is an independent assessment of the appropriateness of the structure and methods used. A second element of validity checking is the comparison of model outputs with what is actually observed in specific instances of the type of situation being modeled. Comparison of model performance with that of other models which are well-based and accepted, for cases to which both apply, could also be part of this type of analysis. Absolute assurance of validity for all possible future uses is, of course, impossible. Replication of reality for a few test cases can only insure that in these particular examples, the model performs as it should, but if the test cases were chosen carefully to be representative of the spectrum of situations to which the model is expected to be applied, then increased confidence in model validity can be obtained.

Beyond the basic validity testing described above, some preliminary sensitivity analyses should be conducted--to identify those parameters having most critical (most sensitive) effect on model outputs, and to ascertain the degree to which model outputs can be expected to vary with input variations. Such sensitivity analyses should also help to determine the limits beyond which application of the model is inappropriate.

1.3 Description of DELCAP

DELCAP is a simulation model, written in the SIMSCRIPT 1.5 computer language, of the airport terminal area including terminal airside operations and those ground operations occurring on the runway surface. DELCAP was designed to focus on operations in the terminal area and to measure throughputs and delays associated with this subsegment of the whole Air Traffic Control (ATC) System. Its output consists of throughput and delay figures. Input includes traffic levels (or the explicit schedules of traffic, or both), the mix and characteristics of aircraft types, the separation rules which apply, the airport runway configuration and its runway operating policies.

In accordance with the modeling philosophy under which DELCAP was designed, in which ease of use is a major criterion, a FORTRAN preprocessing program has been written to allow users to provide inputs in a format less

rigid than that required by SIMSCRIPT programs and to provide a set of nominal input values. The user specifies values for only those input parameters which are to differ from their nominal values. As noted in Appendix A, procedures for selection and values of these nominal inputs have been changed to those most useful for the EPS program.

Figure 1.1 displays the terminal area as seen by the DELCAP model. The aircraft denoted by capital letters are landings; those designated by lower case letters are takeoffs. The landing and takeoff streams are lettered in reverse order of their entrance to the model. (The particular configuration and operating policy shown--a pair of intersecting runways, one handling only takeoffs, the other only landings--is illustrative and should not be taken as a model restriction. Runway configuration is a model <u>input</u>; as will be shown by the exercises reported in Chapters 2 and 3, a wide variety of such configurations can be handled by DELCAP.)

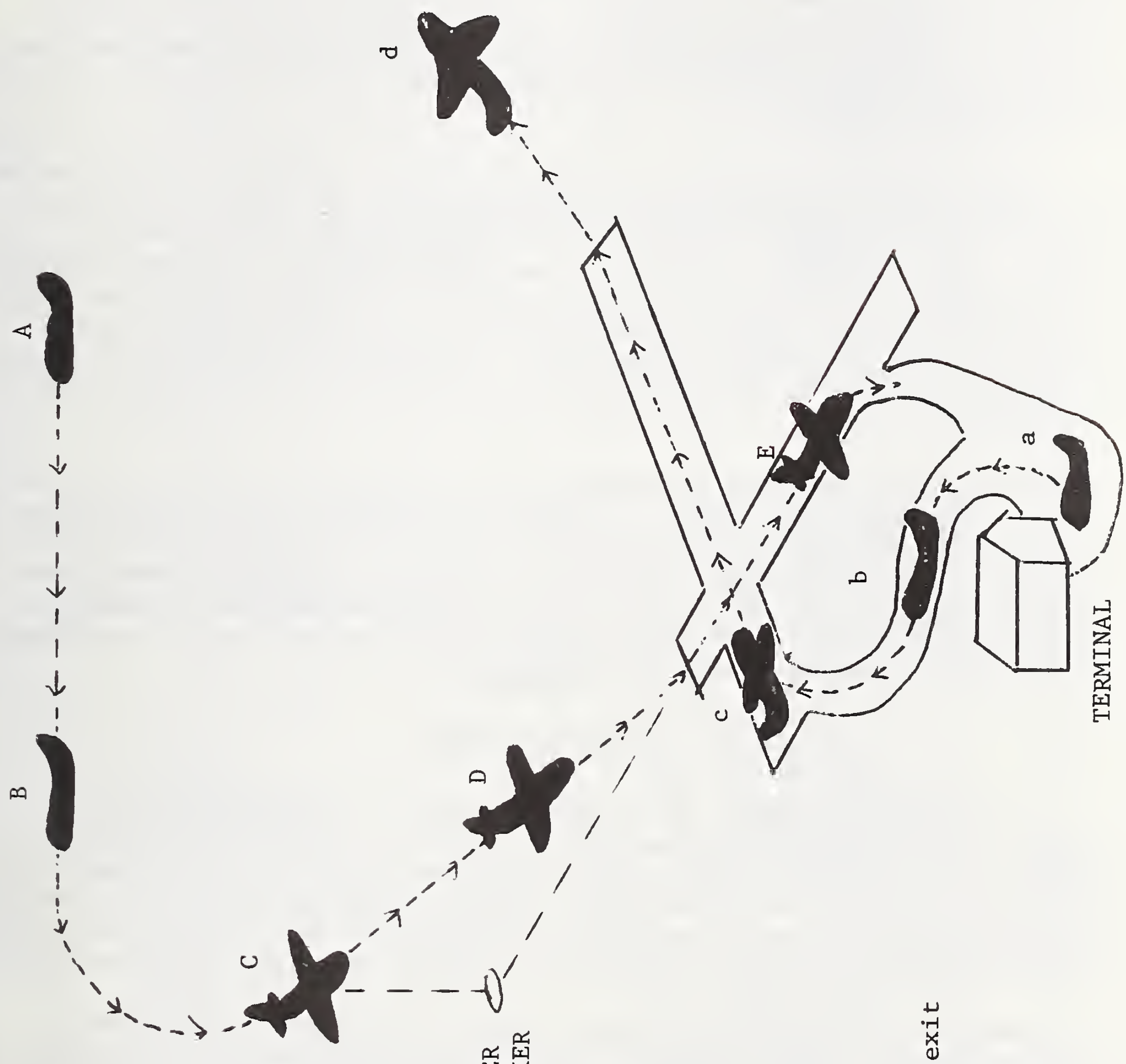
It is convenient to describe DELCAP's treatment of landing and takeoff streams separately, since DELCAP is an event-oriented model (time is incremented to the next "critical event," rather than stepped along at preset intervals) and each critical event in an aircraft's path anticipates the next one along that path. Landings enter the simulation at handoff to tower approach control (A in Figure 1.1). The next critical point along a landing path is the outer marker. DELCAP requires that at least a preset minimum time interval ensue between handoff and the landing's passage of the outer marker. However, the presence of other aircraft in front of A in the landing stream may necessitate that it be placed in a holding pattern or that it fly a longer path to the outer marker, either of which would require extra time. DELCAP does not model the actual route flown by A, but this extra time requirement is imposed by the modeling device of "tying up" the outer marker, i.e., prohibiting A from passing it, until all those in front have done so.

B's final approach can be scheduled once the aircraft in front of B (C in the figure) has passed the outer marker. B must remain separated from C by the required amount (presently 3 miles if C is not a heavy aircraft, 4 miles if both C and B are heavies and 5 miles if C is a heavy but B is not) along the whole final approach path. DELCAP employs the idealization of constant final approach speeds (dependent on aircraft type), and so the acutal separation required between C and B when B crosses the outer marker is either (if C is faster) the minimum required spacing between these aircraft, or (if B is faster) a spacing such that when C touches down B will be at the required minimum separation distance from the end of the runway.* A landing leaves the simulation when it turns off the runway.

* Of course D cannot land as long as E is on the runway surface. That is, in addition to the airborne separation requirements, runway occupancy time also can affect the prescribed separation between D and E. DELCAP includes the "tying up" effects of runway occupancy, though in practice, it is usually the airborne separation which is critical.

FIGURE 1.1

The Terminal Area as Seen by DELCAP



TAKEOFFS
a. at gate
b. taxi from gate to runway
c. start roll
d. lift off

LANDINGS
A. handed off to tower
B. fly from handoff to outer marker
C. cross the outer marker
D. fly final approach
E. land, occupy runway, and exit

Takeoffs enter the simulation about 15 minutes before scheduled departure time. A minimum taxi time between gate and runway is specified. Since in Figure 1.1, landing E has passed the runway intersection, takeoff c can be cleared to start its roll, if takeoff d had sufficient separation from takeoff c; this presently is 2 minutes after d lifts off if d is a heavy and c is not, and is a shorter, constant time interval--approximated as 20 seconds after liftoff--for all other aircraft-type combinations.

Figure 1.2 is a flowchart of the simulation. The bottom box, "choose next operation," represents the implementation of the runway operating policy which determines the sequence of landings and takeoffs on each runway. The two boxes referring to "maintain separation" are implemented in the model by "tying up" critical points in the landing and takeoff paths: the point at which a takeoff starts its roll, the outer marker, and the point at which a landing touches down. A landing or takeoff can be scheduled to take place when no critical point will be tied up when the aircraft reaches it.

The DELCAP model has been designed to provide output of two quantities, namely <u>throughput</u> (the number of operations handled by the facility per time period) and delay. Application of DELCAP is envisaged under two different scenarios. The first is one in which a realistic demand level is stipulated and DELCAP output yields resulting delays and throughputs. In the second scenario, DELCAP is run with high demand levels to estimate the airport's maximum throughput (<u>capacity</u>).

1.4 <u>Validating DELCAP</u>

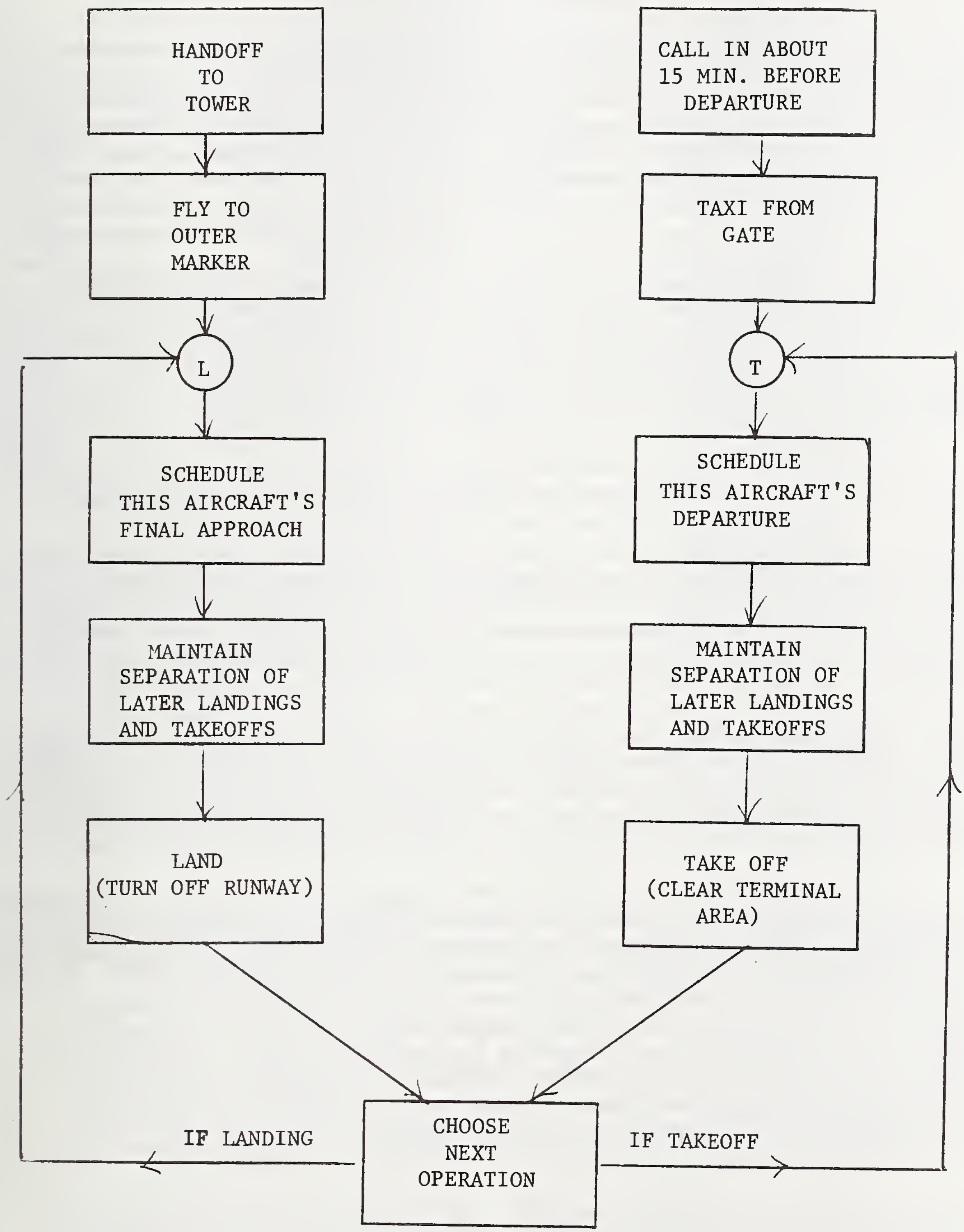
Validation of maximum throughput estimates is reported below in Chapter 2. Testing was concentrated on this case, since the main application which this validation effort supports operates in the second scenario. That application is the computation of EPS's, throughputs which are achievable under heavy traffic conditions, for several of the nation's busiest airports operating under a variety of possible configurations and operating policies.

Chapter 3 recounts an attempt, using currently available data, to validate DELCAP's delay output. This effort, which had to be abandoned for the present because empirical delay figures for that portion of the ATC system modeled by DELCAP were lacking, is reported here as an example of a model exercise, showing the model's versatility and ability to represent actual traffic together with artificially generated traffic. The exercise also illustrates the problems caused by multiple definitions of delay. We do describe (at the end of the chapter) the data collection effort required to support a delay-figure validation analysis.

In Chapter 2, validation exercises employed to test DELCAP under the second scenario above are described in detail, and their results are compared with values obtained from FAA's Air Traffic Service. These tests were designed in consultation with R. Scott of FAA's System Research

FIGURE 1.2

Flowchart of the DELCAP Simulation



and Development Service and R. Woods and R. Tobiason of the Air Traffic Service, to cover that set of configurations most representative of those encountered at major U.S. terminals, including a single runway, two intersecting runway configurations (differing in the placement of the intersection), a pair of close parallel runways, and a pair of close parallels with a third runway crossing the pair. Wide parallels were not included since they can be modeled as two separate single runways. A variety of operating policies were chosen to approximate those used under different traffic situations: when landings balance takeoffs, when landings predominate, and when takeoffs predominate. This diversity also allows comparison of results, to evaluate the sensitivity of DELCAP throughputs to operating policy. The exercises included different mixes of aircraft types, focusing primarily on the fraction of heavy aircraft in the mix since different, larger separations are required behind heavies because of wake turbulence. Other model inputs (such as aircraft characteristics or the length of the final approach path) could also have been varied, but preliminary tests have led us to believe that the three factors mentioned--configuration, operating policy, and aircraft-type mix--are the ones most critically affecting differences in throughput at major U.S. terminals.

Chapter 3 reports the results of an exercise of the model using actual scheduled traffic data from LaGuardia Airport (LGA) for October 25, 1974, plus general aviation traffic generated in a stochastic manner. Simulated delays were compared with the "real" delays experienced by the scheduled aircraft--calculated as the difference between the actual arrival or departure and the corresponding scheduled time. This comparison proved on closer consideration to be improper, "real" delays necessarily being much greater than the simulated ones because they include the effects of interruptions or slow-ups attributable to other parts of the system (not in the LGA terminal area) and to other sources such as equipment - or crew-induced delays. Simulated delays did, however, agree quite well with the delay level reported by the facility, and the shapes of the distributions, "real" and simulated, were very similar. Chapter 3 also contains a discussion of the data required to do a proper delay-figure validation, and suggests methods of acquiring these data.

Chapter 4 contains a conclusion and summary of the report. Appendices A through E document in detail the current version of the DELCAP model and its preprocessor. Appendix A includes a discussion of changes made to the model since its original documentation [1]. Flowcharts and descriptions of all the simulation routines are included in Appendix B. Appendix C lists the variables and arrays used in DELCAP, and Appendix D gives user instructions for preparing preprocessor input. Listings of both programs appear in Appendix E. Appendix F includes a description of the LGA data, together with a discussion of problems encountered in reconciling two data sources for the LGA input.

2. VALIDATION OF DELCAP THROUGHPUT ESTIMATES

2.1 General Description

This chapter documents runs of the DELCAP model designed to test the validity of its throughput calculations under a variety of conditions. The characteristics attributed during these runs to each of three aircraft types--heavy aircraft (over 300,000 lbs. gross weight), small aircraft (most single- and two-engine craft), and medium and larger craft (larger piston aircraft and most jets) -- are described in Table 2.1. These values were obtained from data collected by the Air Traffic Service at O'Hare International Airport (ORD).

Five different runway configurations, representative of those most often encountered and described in greater detail below, were investigated: a single runway, two runways intersecting so as to form a V, two runways intersecting to form an X, a set of close parallels (3000 to 4300 feet apart), and a set of close parallels with a crossing runway. Configurations involving wide parallels are not included in this analysis since the DELCAP model treats wide parallels as two completely separate runways, and as a result, the maximum throughput of a pair of wide parallels is just the sum of the throughputs available from them independently.

For each configuration, operating policies (displayed in Table 2.3) were chosen as most reasonable for each of three arrival/departure mixes: arrivals balancing departures, departures dominant, and arrivals dominant. Each configuration and operating policy was investigated for three aircraft-type mixes, identified by the percentage of heavy aircraft in the mix and described more fully in Table 2.2.

For each configuration, operating policy and aircraft-type mix, the model was run to simulate 20 hours of traffic. The average hourly throughputs (averaged over the sample of 20 hours) of landings, takeoffs and all operations were recorded for each runway and totaled for all runways to permit comparisons among policies, type mixes and configurations.

In Section 2.2 the model's outputs for these cases are described, and evaluated, including the testing of agreement with analytical models (where available) and with ATC experience about how throughput depends on the factors varied. In Section 2.3, the outputs are compared with FAA-supplied data.

2.2 Validation Output

2.2.1 SINGLE RUNWAY

The single runway case has been studied extensively*, and admits analytical expressions for capacity. Two such expressions, one for

* See for example [4], [5], and [6]. Similar formulas to those appearing below appear in these publications, but are derived here again for completeness.

TABLE 2.1

Aircraft Characteristics for Validation Runs

Type Number	Type Description	Speeds (Knots) Landing	Liftoff	Runway Occupancy (Sec) Landing	Takeoff
1	Heavy A/C	124	120	55	33
2	Small A/C	119	90	40	27
3	Category III's (Larger A/C)	120	120	50	32

TABLE 2.2

Three Aircraft-Type Mixes Used

Mix I - 5% Heavies

Type	% in Mix
1	5%
2	17%
3	78%

Mix II - 15% Heavies

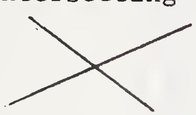
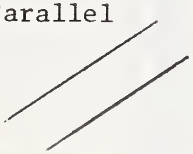
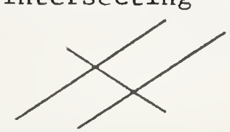
Type	% in Mix
1	15%
2	15%
3	70%

Mix III - 50% Heavies

Type	% in Mix
1	50%
2	9%
3	41%

TABLE 2.3

Configurations and Operating Policies for Validation Runs

Arrival/ Departure Mix	Arrivals = Departures			Departures Predominate			Arrivals Predominate		
% Heavies	5%	15%	50%	5%	15%	50%	5%	15%	50%
Configuration									
Single runway 	Alternate			Two departures between each pair of arrivals			Two arrivals between each pair of departures		
Intersecting 	1. Arrivals on one, Departures on the other 2. Alternate on both			Alternate on one, Departures on the other			Alternate on one, Arrivals on the other		
Intersecting 	1. Arrivals on one, Departures on the other 2. Alternate on both			Alternate on one, Departures on the other			Alternate on one, Arrivals on the other		
Parallel 	1. Arrivals on one, Departures on the other 2. Alternate on both			Alternate on one, Departures on the other			Alternate on one, Arrivals on the other		
Parallel + Intersecting 	Arrivals on one parallel, Departures on the other, Alternate on crossing runway			Departures on one parallel, Alternate on the other two runways			Arrivals on one parallel, Alternate on the other two runways		

a runway handling takeoffs only and the other for the same runway handling landings only, are derived below. As will be seen, DELCAP outputs for these single-runway situations conform closely (as they should) to these theoretical formulas.

To calculate the expected value of the maximum throughput for a single runway handling takeoffs only, under the assumption of a continuous stream of departures in which heavy aircraft appear randomly and constitute a known fraction of all takeoffs, let

N = number of takeoffs per hour,
p = fraction of takeoffs which are heavies,
r = runway occupancy time (hrs.) for heavies,
Δ = average time (hrs.) between takeoffs for non-heavies
δ = average time (hrs.) between takeoffs of two successive heavies (Note that separation rules require a non-heavy to wait 2 minutes after a preceding heavy liftoff before starting its roll.)

Then it follows that:

1. The time between takeoff of a heavy and that of a following non-heavy is $r' = r + 2/60$, the time between takeoffs of heavies is δ, and the time between takeoff of non-heavies is Δ.
2. A fraction p of aircraft following a heavy are heavies; $(1 - p)$ are non-heavies.
3. The expected number of hourly takeoffs by heavies is pN; for non-heavies it is $(1-p)N$.

Thus the following equation (between numbers of hours) holds:

$$pN[p\delta + (1-p)(r')] + (1-p)N\Delta=1$$

or

$$N = 1/[p^2\delta+p(1-p)r' + (1-p)\Delta].$$

For r = 33 seconds, Δ = 54 seconds, and δ = 90 seconds for example, the values in Table 2.1 yield

$$N = 3600/[-64p^2+99p+54].$$

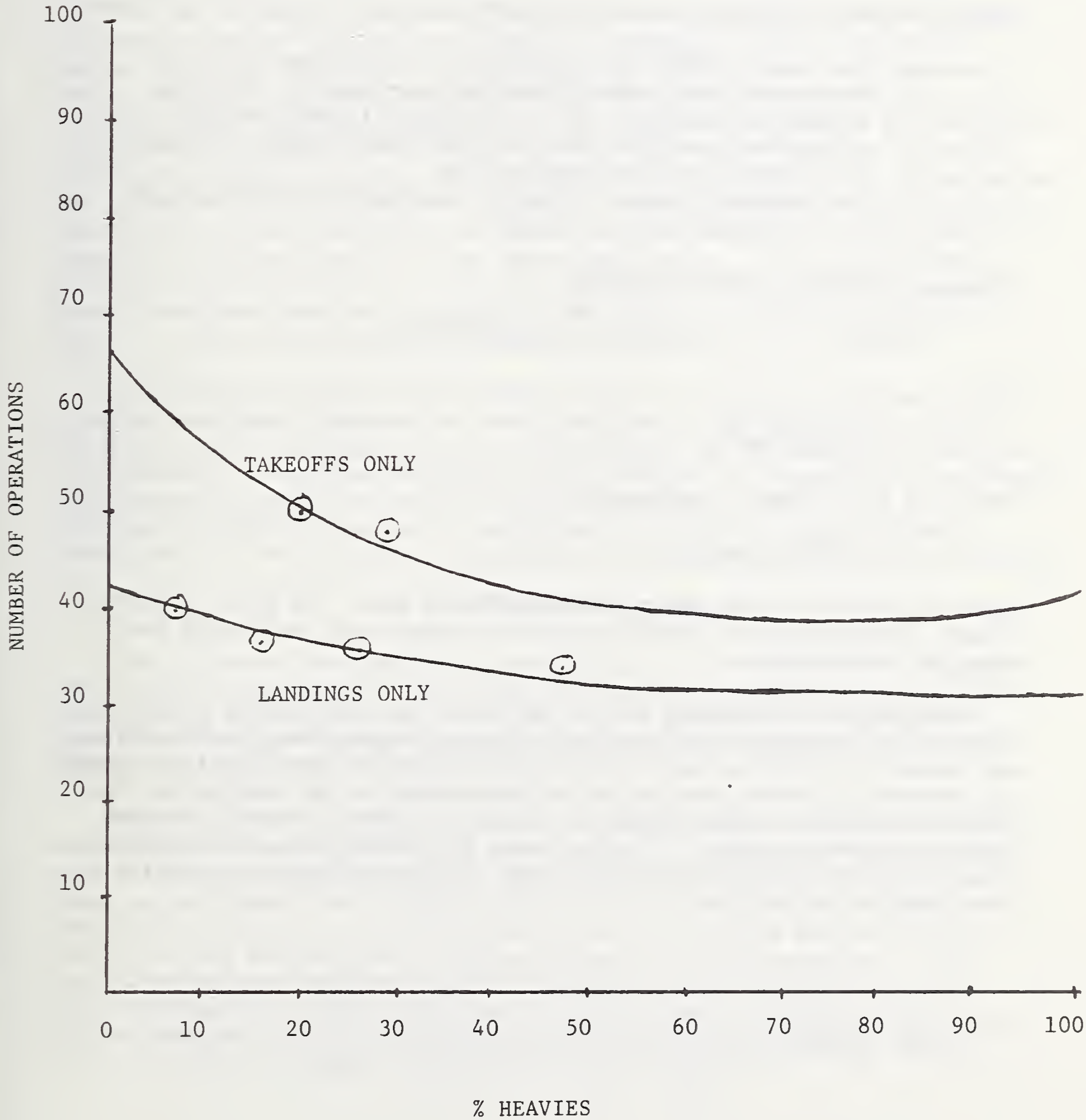
This is plotted as the upper curve in Figure 2.1. The two circled points, at 20 and 30 percent heavies, give the results of actual DELCAP runs and agree well with the corresponding values from the preceding formula.

Similarly, to calculate the expected throughput for a single runway handling landings only, under the further assumption that landing speeds for all aircraft types are equal, let

FIGURE 2.1

Hourly Throughput for a Single Runway

Handling Only Takeoffs or Only Landings



N = number of landings per hour,
p = fraction of landings which are heavies,
s = the landing speed (in knots) for all aircraft types. (Although landing speed does vary among aircraft types, the figures in Table 2.1 indicate that using one value is not a great deviation from reality. More complicated formulas can be derived for the case in which speed depends on aircraft type.)

Then it follows (cf. the separation criteria given in section 1.3) that:

1. The time between the landings of two heavies is $4/s$, between a heavy and a following non-heavy is $5/s$, and between a non-heavy and a following aircraft is $3/s$.
2. A fraction p of the aircraft following a heavy are heavies, a fraction $(1-p)$ are non-heavies.
3. The expected number of hourly landings by heavies is pN; for non-heavies it is $(1-p)N$.

Thus the following equation holds:

$$pN[p(4/s) + (1-p)(5/s)] + (1-p)N(3/s)=1$$

or

$$N = s/(3+2p-p^2).$$

For s = 125 knots, for example,

$$N = 125/(3+2p-p^2),$$

which is plotted on the lower curve in Figure 2.1. The four circled points, output from the DELCAP simulation, agree very well with the expected throughputs.

Analytical expressions can be and have been derived for more complicated operating policies involving dual operations (both landings and takeoffs),* but are much more complex since for some landing aircraft the minimum allowable spacing can be determined by the separation from a preceding landing, rather than the separation from a takeoff occuring between the two landings. In this case, the takeoff is in some sense a "free" contribution to throughput since it does not require an extra interruption in the flow.

* See for example [6].

As part of our validation analysis, three operating policies for a dual use single runway were run using DELCAP. The output from these runs is displayed in Table 2.4. For time periods in which the numbers of arrivals and departures are approximately equal, the operating policy chosen for the single runway seeks to alternate landings and takeoffs. During departure-dominant periods, landings are spaced far enough apart to allow two takeoffs between each pair of landings. For arrival-dominant periods, takeoffs are permitted only between every other pair of landings.

As can be seen by comparing Table 2.4 with Figure 2.1, dual usage of the single runway decreases the takeoff throughput greatly (by about a factor of two). The reason is that landings require more time between operations and dual usage forces some takeoffs to wait for landings. On the other hand, landing throughput is not as greatly degraded by interspersing takeoffs among the landings. Alternation of landings and takeoffs decreased landing throughput by at most 30% from the pure landing operation, and increased total throughput by 40-60%. This agrees well with operating experience: in the absence of stringent takeoff-airspace restrictions, takeoffs are rarely the limiting throughput factor. On the other hand, spacing between landings is critical, and directions such as "maintain speed" sometimes have to be given by controllers to arriving aircraft in order to ensure that minimum spacing is attained.

Validation for the single-runway case was carried out because it is often an important component of more complicated configurations. Wide parallels may be regarded as two single runways in throughput calculations, for instance. Also, some airports may be reduced to essentially the single-runway configuration during IFR weather or outages. Still, the primary advantage of DELCAP lies in its applicability to more complex runway situations for which analytic expressions are much more difficult to obtain.

2.2.2 INTERSECTING RUNWAYS

Two different configurations consisting of a pair of intersecting runways were investigated: one with the intersection 2000 feet from the ends of each of the runways (representing the near-intersection or "V" case), the second with the intersection 4000 feet from the ends of each runway (a configuration shaped like an "X").

During periods in which arrivals and departures are roughly balanced, two different operating policies were chosen as reasonable: the first of them alternates landings and takeoffs on both runways, while the second reserves one runway for landings only and the other just for takeoffs. (The second policy can result in lower capacity, but is easier for the controller and probably more representative of actual practice.) For departure-dominant periods, one of the runways handles takeoffs only, with landings and takeoffs alternated on the other. Similarly, for arrival-dominant periods, one runway is set aside for landings only, while landings and takeoffs alternate on the other.

TABLE 2.4

Single Runway Throughput (per Hour)

OPERATING POLICY	5% HEAVIES LAND	5% HEAVIES TAKEOFF	5% HEAVIES TOTAL	15% HEAVIES LAND	15% HEAVIES TAKEOFF	15% HEAVIES TOTAL	50% HEAVIES LAND	50% HEAVIES TAKEOFF	50% HEAVIES TOTAL
ARRIVALS = DEPARTURES: ALTERNATE	28.2	28.2	56.4	27.3	27.3	54.6	26.3	26.3	52.6
DEPARTURES PREDOMINATE: TWO TAKEOFFS BETWEEN EACH PAIR OF LANDINGS	19.6	39.2	58.9	18.6	37.2	55.4	17.2	34.4	51.6
ARRIVALS PREDOMINATE: TWO LANDINGS BETWEEN EACH PAIR OF TAKEOFFS	32.8	16.4	49.3	31.7	15.8	47.5	29.2	14.5	43.7

Each intersecting-runway configuration was run both with and without the requirement that operations on one runway be separated from those on the other. In the less restrictive case, the only interaction imposed was that a landing's touchdown or a takeoff's start-of-roll on one runway could not occur in the period between a landing or start-of-roll of an aircraft on the other runway and the time that aircraft passed the intersection. In the other case, in addition to the preceding prohibition, landings on one runway had to be separated by the required 3, 4 or 5 miles from landings on the other, and also by 2 miles from preceding takeoffs on the other. Two separate tables are given for each of the V and X intersection cases (see Tables 2.5-2.8), one including the second separation requirement (described as "with interference") and one without.*

The interference requirement reduces throughput by 3 to 45 percent, with the lower reduction occurring when takeoffs are allowed on only one runway (i.e., the middle two operating policies in the Tables). It is probably very unusual for landings to be allowed on both runways of an intersecting pair. In fact, the "landings on one, takeoffs on the other" policy is the one most often employed in practice for an intersecting pair, if the runways are of comparable length. When one is longer than the other, then segregation by aircraft type, rather than by operation, is often employed, and something approaching the policy of alternating operations might be achieved. In this case segregation by type (and thus by landing speed) would tend to decrease actual interlanding separations (by reducing gaps due to a slow plane following a faster one), resulting in slightly higher throughputs than those given in Tables 2.5-2.8. With interference, the maximum number of landings -- which occurs for the near intersection for the policy allowing one runway to handle only landings and the other only takeoffs, and occurs for the far intersection for the policy allowing landings on both runways with takeoffs interspersed on one -- is actually about the same as the number of landings on the landings-only runway alone (under the same policies) when there is no interference.

The difference between 5 and 50 percent heavies in the aircraft type mix leads to a decrease of 6 to 24 percent in total throughput, with the larger differences generally occurring for the policy having only landings on one runway and only takeoffs on the other. To explain this, note that with landings spaced at 5 miles (as for a non-heavy aircraft following a heavy), a takeoff can occur between the two landings without affecting either. The pure-landing/pure-takeoff policy does not exploit this, so that the full brunt of the increased separation is felt. Policies employing dual-use runways are in a better position to utilize these extra spaces.

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* Output for the "pure arrival, pure departure" case in Tables 2.5 through 2.9 differs from that reported in [2] because of an intervening model modification allowing policies which coordinate operations on different runways.

TABLE 2.5

Hourly Throughput for Near Intersection (V) With Interference

OPERATING POLICY	RUNWAY	5% HEAVIES			15% HEAVIES			50%HEAVIES		
		LAND	TAKEOFF	TOTAL	LAND	TAKEOFF	TOTAL	LAND	TAKEOFF	TOTAL
ARRIVALS = DEPARTURES	1	16.3	16.3	32.6	15.7	15.7	31.5	14.4	14.5	28.9
ALTERNATE ON BOTH	2	16.3	16.3	32.6	15.7	15.7	31.4	14.5	14.5	29.0
	TOTAL	32.6	32.6	65.3	31.5	31.4	62.9	28.9	29.0	57.9
ARRIVALS = DEPARTURES	1	0.0	37.4	37.4	0.0	34.3	34.3	0.0	30.1	30.1
RUNWAY 1-TAKEOFFS ONLY	2	37.4	0.0	37.4	34.4	0.0	34.4	30.1	0.0	30.1
RUNWAY 2-LANDINGS ONLY	TOTAL	37.4	37.4	74.8	34.4	34.3	68.7	30.1	30.1	60.2
DEPARTURES PREDOMINATE	1	0.0	44.4	44.4	0.0	41.4	41.4	0.0	37.8	37.8
RUNWAY 1-TAKEOFFS ONLY	2	22.4	22.4	44.9	22.1	22.0	44.1	21.7	21.6	43.3
RUNWAY 2-ALTERNATE	TOTAL	22.4	66.8	89.3	22.1	63.4	85.5	21.7	59.4	81.1
ARRIVALS PREDOMINATE	1	21.6	0.0	21.6	20.3	0.0	20.3	18.2	0.0	18.2
RUNWAY 1-LANDINGS ONLY	2	14.7	14.7	29.4	14.0	14.0	28.0	13.1	13.1	26.3
RUNWAY 2-ALTERNATE	TOTAL	36.3	14.7	51.0	34.3	14.0	48.3	31.4	13.1	44.5

TABLE 2.6

Hourly Throughput for Near Intersection (V) Without Interference

OPERATING POLICY	RUNWAY	5% HEAVIES			15% HEAVIES			50% HEAVIES		
		LAND	TAKEOFF	TOTAL	LAND	TAKEOFF	TOTAL	LAND	TAKEOFF	TOTAL
ARRIVALS = DEPARTURES	1	28.1	28.1	56.2	27.1	27.1	54.3	26.2	26.2	52.4
ALTERNATE ON BOTH	2	28.0	28.1	56.1	27.2	27.2	54.5	26.1	26.1	52.3
	TOTAL	56.2	56.2	112.4	54.4	54.4	108.8	52.3	52.4	104.7
ARRIVALS = DEPARTURES	1	0.0	38.6	38.6	0.0	36.5	36.5	0.0	32.0	32.0
RUNWAY 1-TAKEOFFS ONLY	2	38.6	0.0	38.6	36.5	0.0	36.5	32.0	0.0	32.0
RUNWAY 2-LANDINGS ONLY	TOTAL	38.6	38.6	77.2	36.5	36.5	73.1	32.0	32.0	64.0
DEPARTURES PREDOMINATE	1	0.0	63.8	63.8	0.0	54.7	54.7	0.0	46.7	46.7
RUNWAY 1-TAKEOFFS ONLY	2	27.9	28.0	55.9	27.1	27.1	54.3	26.1	26.1	52.3
RUNWAY 2-ALTERNATE	TOTAL	27.9	91.8	119.8	27.1	81.8	119.0	26.1	72.9	99.0
ARRIVALS PREDOMINATE	1	38.1	0.0	38.1	35.9	0.0	35.9	31.6	0.0	31.6
RUNWAY 1-LANDINGS ONLY	2	28.0	28.0	56.0	27.1	27.1	54.2	26.1	26.1	52.2
RUNWAY 2-ALTERNATE	TOTAL	66.1	28.0	94.1	63.1	27.1	90.2	57.7	26.1	83.8

TABLE 2.7

Hourly Throughput for Far Intersection (X) With Interference

		5% HEAVIES			15% HEAVIES			50% HEAVIES		
OPERATING POLICY	RUNWAY	LAND	TAKEOFF	TOTAL	LAND	TAKEOFF	TOTAL	LAND	TAKEOFF	TOTAL
ARRIVALS = DEPARTURES	1	15.8	15.8	31.6	15.3	15.3	30.7	14.1	14.1	28.3
ALTERNATE ON BOTH	2	15.8	15.8	31.6	15.3	15.3	30.6	14.2	14.1	28.3
	TOTAL	31.6	31.6	63.2	30.6	30.7	61.3	28.3	28.3	56.6
ARRIVALS = DEPARTURES	1	0.0	33.6	33.6	0.0	31.6	31.6	0.0	28.7	28.7
RUNWAY 1-TAKEOFFS ONLY	2	33.6	0.0	33.6	31.5	0.0	31.6	28.7	0.0	28.7
RUNWAY 2-LANDINGS ONLY	TOTAL	33.6	33.6	67.3	31.5	31.6	63.1	28.7	28.7	57.4
DEPARTURES PREDOMINATE	1	0.0	42.7	42.7	0.0	40.0	40.0	0.0	36.8	36.8
RUNWAY 1-TAKEOFFS ONLY	2	21.5	21.5	43.1	21.4	21.4	42.8	21.3	21.3	42.7
RUNWAY 2-ALTERNATE	TOTAL	21.5	64.2	85.8	21.4	61.4	82.8	21.3	58.1	79.5
ARRIVALS PREDOMINATE	1	21.2	0.0	21.2	20.0	0.0	20.0	18.0	0.0	18.0
RUNWAY 1-LANDINGS ONLY	2	14.2	14.2	28.4	13.7	13.7	27.4	12.9	12.9	25.8
RUNWAY 2-ALTERNATE	TOTAL	35.4	14.2	49.6	33.7	13.7	47.4	30.9	12.9	43.8

TABLE 2.8

Hourly Throughput for Far Intersection (X) Without Interference

OPERATING POLICY	RUNWAY	5% HEAVIES			15% HEAVIES			50% HEAVIES		
		LAND	TAKEOFF	TOTAL	LAND	TAKEOFF	TOTAL	LAND	TAKEOFF	TOTAL
ARRIVALS = DEPARTURES	1	27.2	27.2	54.5	26.3	26.2	52.5	25.4	25.4	50.9
ALTERNATE ON BOTH	2	27.2	27.3	54.5	26.4	26.4	52.8	25.5	25.4	50.9
	TOTAL	54.5	54.5	109.0	52.7	52.7	105.4	50.9	50.9	101.8
ARRIVALS = DEPARTURES	1	0.0	37.7	37.7	0.0	34.9	34.9	0.0	30.6	30.6
RUNWAY 1-TAKEOFFS ONLY	2	37.8	0.0	37.8	34.9	0.0	34.9	30.7	0.0	30.7
RUNWAY 2-LANDINGS ONLY	TOTAL	37.8	37.7	75.5	34.9	34.9	69.8	30.7	30.6	61.3
DEPARTURES PREDOMINATE	1	0.0	58.0	58.0	0.0	51.7	51.7	0.0	44.9	44.9
RUNWAY 1-TAKEOFFS ONLY	2	27.4	27.3	54.7	26.6	26.6	53.3	25.6	25.6	51.2
RUNWAY 2-ALTERNATE	TOTAL	27.4	85.3	112.7	26.6	78.4	105.0	25.6	70.5	96.1
ARRIVALS PREDOMINATE	1	38.0	0.0	38.0	35.3	0.0	35.3	30.8	0.0	30.8
RUNWAY 1-LANDINGS ONLY	2	26.3	26.4	52.7	26.1	26.0	52.1	25.5	25.5	51.0
RUNWAY 2-ALTERNATE	TOTAL	64.3	26.4	90.7	61.4	26.0	87.4	56.3	25.5	81.8

The location of the intersection, far rather than near, causes a greater reduction in takeoff throughput than in landing throughput. This is to be expected, since runway occupancy time is not a critical factor in interlanding spacing, but plays a much greater role in constraining takeoffs. The intersection's location, however, has much less effect than does operating policy.

In summary, the simulated behavior of a pair of intersecting runways is very much as one would expect from logic and real-world experience. The throughput levels produced by DELCAP may be higher than those usually observed because two of the four operating policies simulated allow landings on both runways, a situation atypical in practice. Thus the predicted throughputs for the pure-landing/pure-takeoff strategy perhaps represent the most realistic estimates.

2.2.3 CLOSE PARALLELS

A parallel runway configuration was run under the restriction that landings on one runway must be separated by 3, 4 or 5 miles from landings on the other, and by 2 miles from preceding takeoffs on the other. (This restriction presently applies to parallels whose center lines are separated by 3000-4300 feet.) The results are given in Table 2.9.

During periods when the numbers of arrivals and departures are about the same, the operating policies of choice are either to alternate landings and takeoffs on both runways or to reserve one runway exclusively for landings and the second just for takeoffs, alternating operations on the two. When departures dominate, one runway is reserved exclusively for them, while landings and takeoffs alternate on the other runway. For periods in which arrivals predominate, one runway is restricted to landings only, while landings and takeoffs alternate on the other.

Comparison with Table 2.6 shows that the performance of a pair of close parallel runways very closely resembles that of a "V" intersection with interference, and many of the remarks made for that earlier case also apply here. Since runway occupancy time is not a critical factor in interlanding spacing and since the required separations between landings on the two runways are the same as for one runway, the maximum landing throughput for a set of parallels is not much larger than that for a single runway with two landings between each pair of takeoffs (see Table 2.4). Alternating landings and takeoffs on both runways yields about a 16 percent improvement over the single runway, gained presumably because runway occupancy time has no effect on the other runway's operations.

When takeoffs predominate, landings are spaced far enough apart to allow extra takeoffs on the other runway, and a comparison with Figure 2.1 shows that the number of takeoffs is at most 11 percent less than a single runway handling only takeoffs. Coordinating operations on the two runways, so that a landing on one alternates with a takeoff on the

TABLE 2.9

Hourly Throughput for Close Parallels

					15% HEAVIES			50% HEAVIES		
OPERATING POLICY	RUNWAY	LAND	TAKEOFF	TOTAL	LAND	TAKEOFF	TOTAL	LAND	TAKEOFF	TOTAL
ARRIVALS = DEPARTURES	1	16.3	16.4	32.7	15.7	15.7	31.5	14.5	14.5	29.0
ALTERNATE ON BOTH RUNWAYS	2	16.3	16.3	32.7	15.7	15.7	31.5	14.5	14.5	29.0
	TOTAL	32.7	32.7	65.4	31.5	31.5	63.0	29.0	29.0	58.0
ARRIVALS = DEPARTURES	1	0.0	37.6	37.6	0.0	34.7	34.7	0.0	30.5	30.5
ALTERNATE LANDING ON RUNWAY 2 WITH TAKEOFF ON RUNWAY 1	2	37.6	0.0	37.6	34.7	0.0	34.7	30.5	0.0	30.5
	TOTAL	37.6	37.6	75.3	34.7	34.7	69.5	30.5	30.5	61.0
DEPARTURES PREDOMINATE	1	0.0	54.0	54.0	0.0	49.0	49.0	0.0	42.3	42.3
RUNWAY 1-TAKEOFFS ONLY	2	27.5	0.0	27.5	26.2	0.0	26.2	23.9	0.0	23.9
RUNWAY 2-LANDINGS ONLY	TOTAL	27.5	54.0	81.6	26.2	49.0	75.2	23.9	42.3	66.2
ARRIVALS PREDOMINATE	1	16.5	16.5	33.1	16.0	16.0	32.0	13.8	13.8	27.6
RUNWAY 1-ALTERNATE RUNWAY 2-LANDINGS ONLY	2	21.0	0.0	21.0	20.0	0.0	20.0	18.7	0.0	18.7
	TOTAL	37.7	16.5	54.2	36.1	16.0	52.1	32.5	13.8	46.3

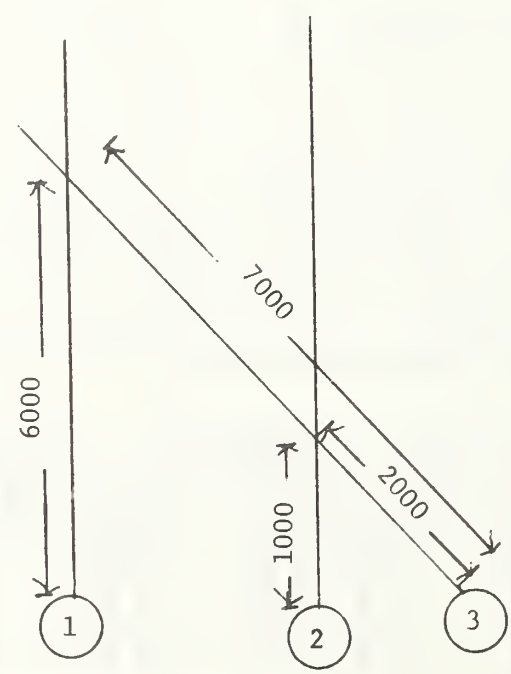
other, results in a decrease of only 8 percent in total throughput but an increase of 28 to 37 percent in the number of landings. In fact the second policy, involving cooperating pure operations, suffers only a 6 to 8 percent reduction in the number of landings from the number operating on a single runway handling landings only. The addition of the second of a close parallel pair of runways thus buys some additional throughput, 16 to 34 percent for periods when the numbers of arrivals and departures balance and 37 percent when departures dominate. During arrival-dominated periods, however, only 9 percent increase in total throughput is observed.

2.2.4 CLOSE PARALLELS WITH AN INTERSECTING RUNWAY

The runway configuration for these runs is pictured in Figure 2.2. For time periods in which arrivals and departures are balanced, the operating policy chosen reserves one of the parallel runways (1) for takeoffs, the other parallel (2) for landings and alternates landings and takeoffs on the crossing runway (3). For departure-dominant periods one of the parallels (1) is reserved for takeoffs and landings and takeoffs are alternated on the other two runways. For arrival-dominant periods one of the parallels (1) is reserved for landings, and landings and takeoffs are alternated on the other two. These last two policies are probably unrealistically complicated for a real control situation, but have been simulated to show possible throughput advantages from dual operations.

FIGURE 2.2

Close Parallels with an Intersecting Runway



Tables 2.10 and 2.11 summarize the results of these runs. Separation requirements for aircraft on the two parallels are those described in Section 2.2.3 for close parallels. For the runs reported in Table 2.10, no interference requirements were put on the intersecting runway, so that takeoffs and landings on it were restricted only by runway occupancy on the other runways. This, of course, does not represent the real requirement when all runways are operated under IFR conditions, but may be more reflective of actual operating practice if the crossing runway is used primarily for smaller VFR aircraft. The runs reported in Table 2.11 had all interference restrictions in force.

Without the interference requirement in effect, the third runway increases landing throughput by 50 to 79 percent and takeoff throughput by 13 to 33 percent over the levels reported in Table 2.9 for parallel runways operated in the pure landing/pure takeoff mode. This increase does not accrue when the interference requirement is in force, since as noted earlier, that requirement means that maximum landing throughput is effectively that of a single runway.

The three different operating policies chosen differ by 17 to 34 percent in landing throughput, but by a factor of almost 3 in takeoff throughput, again demonstrating that meeting takeoff demand is less difficult and less critical than meeting landing demand, a fact well-recognized by controllers. This is shown even more dramatically by the observation that the first and second policies displayed in Table 2.10 differ only in that the first one restricts runway 2 to landings only (rather than dual use), but the landing throughput is almost the same in the two cases.

2.2.5 ANALYSIS OF RESULTS

The preceding section described output from applications of the DELCAP model to a variety of common runway configurations, demonstrating the model's versatility and its ability to represent those airport facilities for which further computerized throughput analysis is desired. DELCAP has also been run on the Chicago O'Hare (ORD) configuration depicted in Figure 2.3. In addition, the model is capable of handling even more complex configurations than this, with many more runways and more complicated interactions among them.

Table 2.10

Hourly Throughput for Close Parallels Plus an Intersecting Runway Without Interference

OPERATING POLICY	RUNWAY	5% HEAVIES			15% HEAVIES			50% HEAVIES		
		LAND	TAKEOFF	TOTAL	LAND	TAKEOFF	TOTAL	LAND	TAKEOFF	TOTAL
ARRIVALS = DEPARTURES	1	0.0	40.3	40.3	0.0	36.6	36.6	0.0	34.0	34.9
RUNWAY 1-TAKEOFFS ONLY	2	21.2	0.0	21.2	21.3	0.0	21.3	21.6	0.0	21.6
RUNWAY 2-LANDINGS ONLY	3	20.9	20.9	41.8	20.8	20.8	41.6	21.0	21.0	42.1
RUNWAY 3-ALTERNATE	TOTAL	42.2	61.2	103.4	42.1	57.5	99.6	42.6	56.0	98.7
DEPARTURES PREDOMINATE	1	0.0	43.2	43.2	0.0	39.3	39.3	0.0	35.6	35.6
RUNWAY 1-TAKEOFFS ONLY	2	21.5	21.4	42.9	20.6	20.6	41.2	20.2	20.1	40.3
RUNWAY 2-ALTERNATE RUNWAY 3-ALTERNATE	3	22.8	22.8	45.6	22.9	22.9	45.8	22.0	22.0	44.0
	TOTAL	44.3	87.5	131.8	43.5	82.8	126.3	42.2	77.7	119.9
ARRIVALS PREDOMINATE	1	19.3	0.0	19.3	17.9	0.0	17.9	16.5	0.0	16.5
RUNWAY 1-LANDINGS ONLY	2	14.7	14.7	29.5	14.4	14.4	28.9	12.9	13.0	25.9
RUNWAY 2-ALTERNATE RUNWAY 3-ALTERNATE	3	15.2	15.2	30.4	15.3	15.3	30.7	14.5	14.5	29.0
	TOTAL	49.3	29.9	79.2	47.7	29.8	77.5	43.9	27.5	71.5

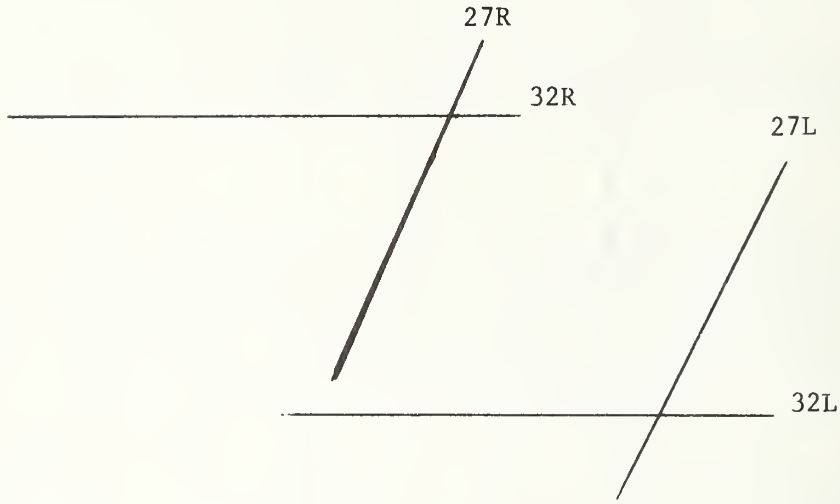
TABLE 2.11

Hourly Throughput for Close Parallels Plus an Intersecting Runway With Interference

OPERATING POLICY	RUNWAY	5% HEAVIES			15% HEAVIES			50% HEAVIES		
		LAND	TAKEOFF	TOTAL	LAND	TAKEOFF	TOTAL	LAND	TAKEOFF	TOTAL
ARRIVALS = DEPARTURES	1	0.0	26.0	26.0	0.0	25.3	25.3	0.0	24.0	24.0
RUNWAY 1-TAKEOFFS ONLY	2	14.0	0.0	14.0	14.6	0.0	14.6	14.0	0.0	14.4
RUNWAY 2-LANDINGS ONLY	3	12.5	12.5	25.1	12.0	12.0	24.0	11.4	11.4	22.8
RUNWAY 3-ALTERNATE	TOTAL	26.5	38.6	65.1	26.7	37.3	64.0	25.8	35.4	61.3
DEPARTURES PREDOMINATE	1	0.0	30.4	30.4	0.0	26.1	26.1	0.0	24.6	24.6
RUNWAY 1-TAKEOFFS ONLY	2	12.7	12.7	25.4	11.9	11.8	23.7	11.6	11.5	23.1
RUNWAY 2-ALTERNATE RUNWAY 3-ALTERNATE	3	12.7	12.7	25.4	11.8	11.8	23.7	11.5	11.5	23.0
	TOTAL	25.4	55.8	81.3	23.7	49.8	73.5	23.1	47.7	70.8
ARRIVALS PREDOMINATE	1	15.3	0.0	15.3	14.3	0.0	14.3	12.6	0.0	12.6
RUNWAY 1-LANDINGS ONLY	2	9.4	9.4	18.9	9.5	9.4	18.9	9.0	9.0	18.1
RUNWAY 2-ALTERNATE RUNWAY 3-ALTERNATE	3	9.4	9.4	18.9	9.4	9.4	18.8	8.9	8.9	17.8
	TOTAL	34.2	18.9	53.1	33.2	18.8	52.0	30.5	17.9	48.5

FIGURE 2.3

O'Hare Four-Runway Configuration



In the analyses reported above, the model was also exercised under different aircraft-type mixes and different arrival/departure ratios to demonstrate its ability to model these variations successfully. Changing the fraction of heavy aircraft from 5 to 50 percent decreases landing throughput (per runway per hour) by from 0 to 20 percent with an average decrease of about 12 percent, representing from 0 to 8 landings per runway and averaging about 4. Hourly takeoff throughput per runway is decreased more severely - from 0 to 28 percent, averaging 12 percent and representing a decrease of from 0 to 19 takeoffs (averaging 7).

As noted above, operating policy has almost as great an effect on throughput as does runway configuration. The influence of policy, a critical factor in actual operations, is probably somewhat exaggerated by the simulation when used to estimate maximum throughputs. In the simulation, operating policy is rigidly imposed. Whereas in a real situation a controller might run overflow takeoffs on a runway normally handling landings only, or divert a landing to a runway generally reserved for takeoffs, the simulation does not have this flexibility. In practice, the controller's extra leeway should allow him to exceed the capacity levels predicted by the model and therefore should allow for contingencies unforeseen by model assumptions, such as more serious bunching of arrivals and departures, or gaps caused by pilot decisions over which the ATC system has little control. The comparative rigidity of the DELCAP model's handling of operating policy should not seriously affect its usefulness as a tool in establishing EPS's, if care is taken in its application to ensure the most appropriate policy is chosen for simulation.

The DELCAP simulation as now constituted assumes interlanding spacings of exactly 3, 4 or 5 miles as well as fixed and constant runway occupancy times, assumptions which are unrealistic. However, since real separations and runway occupancies may be either less or greater than the nominal values, it is unclear in which direction or to what extent these assumptions bias the resultant throughput values. Although it would be a relatively simple matter to represent these factors in a stochastic manner, it is not at all clear that much additional accuracy in throughput calculations would be gained, particularly since results are averaged over a period of 20 hours.

Throughputs calculated by DELCAP vary with operating policy, configuration and mix in the expected direction and agree quite well in magnitude with observed levels. (A more complete demonstration of this last point follows in the next section.) There are, however, a number of instances in which model outputs are higher than those actually attained at most installations. These involved the simulation of operating policies more complex in their control requirements than the policies in present use, so that empirical data with which to compare these outputs are lacking. For example, it would be unusual for a pair of intersecting or close parallel runways to be operated for any prolonged time with landings on both, unless one runway handled primarily smaller aircraft making visual approaches. This also holds true for the "parallels with crossing runway" configuration; most airports with such a configuration would use the parallels for landings and takeoffs (on separate runways) of larger aircraft, with the crossing runway allocated to lighter aircraft as required. The DELCAP throughputs reported above, therefore, in part require demand levels and controller capabilities which are unlikely to be sustained over long periods. More practical capacity levels are associated with those policies which reserve main runways for pure operations and shorter crossing runways for mixed operations of lighter aircraft.

2.3 Comparisons of Model Output With Available Data

Table 2.12 reports IFR throughput figures for a variety of runway configurations at several airports, as computed by a theoretical procedure now under development by the FAA Air Traffic Service, as estimated by staff at the facility, and finally, as found using a version of the theoretical procedure devised by the FAA to account for local variations. The figures vary from facility to facility for the same configuration because of differences in aircraft-type mix and in other special characteristics such as air space restrictions (at JFK, for example). Differences between the theoretical and the modified standard values range from 4 to 19 percent and average 11 percent, so that one can regard as acceptable similar differences between these values and those produced by the model.

TABLE 2.12

Throughput for Several Configurations at Selected Airports

Configuration Class	Theoretical	Facility Estimates	Modified Standard
Wide Parallels			
· JFK IFR-Pure*	74	70	71
· MIA - Mixed	106	75	100
· ATL - Mixed	114	91	98
· ORD - Mixed	104	90	92
Close Parallels			
· JFK IFR-Pure	60	50	52
· PHL - Pure	68	52	57
4 R/W's ORD			
2 Pure Approach 2 Pure Departure	152	135	137

* A "pure" operation is one handling only takeoffs or only landings. Parallels operated in a pure policy have one runway only for landings and a second for takeoffs only. "Mixed" operations refers to a policy allowing both landings and takeoffs on a runway.

In comparing the figures in Table 2.12 with DELCAP outputs, we have modified the latter to take into account the fact that takeoff capacity is rarely restricted and that the numbers in Table 2.12 are those sustainable over an extended period of time during which the total numbers of arrivals and departures are approximately equal. Whenever simulated takeoffs substantially outnumber landings, the maximum total throughput as calculated by DELCAP does not correspond to such a sustainable situation, and a better approximation to realistic total throughput is twice the calculated landing throughput. Table 2.13 reports throughputs thus obtained from DELCAP for configurations similar to those in Table 2.12. (Most of these numbers are taken directly from tables in the previous sections.) Throughput for the

TABLE 2.13

Sustainable Throughput Estimated by DELCAP

CONFIGURATION AND POLICY	5% HEAVIES				15% HEAVIES				50% HEAVIES			
	LAND	TAKEOFF	TOTAL	SUSTAIN	LAND	TAKEOFF	TOTAL	SUSTAIN	LAND	TAKEOFF	TOTAL	SUSTAIN
WIDE PARALLELS PURE	38.8	61.3	100.1	77.6	36.8	53.9	90.7	73.6	32.3	45.7	78.0	64.6
WIDE PARALLELS MIXED	56.4	56.4	112.8	112.8	54.6	54.6	109.2	109.2	52.6	52.6	105.2	105.2
CLOSE PARALLELS PURE	37.6	37.6	75.3	75.3	34.7	34.7	69.5	69.5	30.5	30.5	61.0	61.0
2 WIDE PARALLELS (ORD) PURE	76.4	73.3	152.7	152.7	71.4	71.4	142.9	142.9	62.7	62.7	125.3	125.3

TABLE 2.14

Comparison of FAA Theoretical Throughput Estimates With Those Calculated By DELCAP

Configuration Class	Theoretical	DELCAP
Wide Parallels		
. JFK IFR-Pure*	74	78
. MIA-Mixed	106	113
. ATL-Mixed	114	113
. ORD-Mixed	104	109
Close Parallels		
. JFK IFR-Pure	60	61
. PHL-Pure	68	75
4 R/W's ORD		
2 Pure Approach 2 Pure Departure	152	143

wide parallels with pure operations is calculated by adding the throughput for a single runway with only landings, to that for a single runway with only takeoffs.* Throughput for wide parallels used in mixed operations is calculated as twice the throughput for a single runway serving alternating landings and takeoffs. Throughput for the ORD 4-parallels case pictured in Figure 2.3 is estimated as the sum of throughputs for a near-intersection ("V") configuration and a far intersection pair of runways (both pairs without interference). The FAA theoretical values are compared with the DELCAP Estimates for the appropriate aircraft type mixes in Table 2.14.

Differences in throughput among airports depend in part on the aircraft-type mix. The mix at JFK contains approximately 43 percent heavies, while that at the other airports is much lower. (At ORD, for instance, there are about 16 percent heavies.) For most of the airports of concern here, small aircraft account for a relatively small proportion of traffic (except for PHL where they account for about 40 percent). Therefore, for most airports the throughput figures are more like those reported for 5 and 15 percent heavies.

In the case of wide parallels and pure operations, values in the two tables agree quite well. Whereas the theoretical value of 74 operations per hour agrees exactly with the DELCAP value for 15 percent heavies, the value of 65 from DELCAP for 50 percent heavies is more appropriate since JFK has over 40 percent heavies. Linear interpolation (of 40 percent between 15 and 50 percent) yields about 68, slightly lower than the final figure of 71 (surprisingly, since one would normally expect the model, requiring perfect controllability, to estimate higher than actual values), but still within 5 or 6 percent of the modified performance standard.

In the case of wide parallels under mixed operations, DELCAP maximum throughput values vary from 105 for 50 percent heavies to 113 for 5 percent heavies, agreeing very well with the 104 to 114 theoretical values for the three airports using this operating policy. The most applicable DELCAP values are for the 5 to 15 percent heavies for these three airports, meaning that DELCAP estimates are 5 to 7 operations high for MIA (Miami International) and ORD (Chicago O'Hare International), and one operation low for ATL (Atlanta), but still within 5 to 6 percent of the theoretical values determined by the FAA.

DELCAP values agree very well with the theoretical values for close parallels. The DELCAP throughput of 61 operations at 50 percent heavies matches closely the theoretical value of 60 for JFK, which has a large percent of heavies in its mix. The PHL theoretical value of 68 is closely approximated by the DELCAP-computed value of 69.5 for 15 percent heavies. In both cases the DELCAP values are slightly high (1 or 2 percent) but the fraction of heavies at PHL is probably closer to the 5 percent level, in which case the DELCAP figure is 10 percent high.

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* The numbers in Table 2.13 for this case are obtained from runs not included among those reported earlier.

Throughput calculated by DELCAP for the 4-runway ORD case lies between the modified standard and the theoretical value in Table 3.2. Note that the DELCAP throughputs used for this analysis are those without interference. (If values from runs with interference were used, the DELCAP estimates would be somewhat lower.) Discussions with FAA personnel familiar with the ORD operation indicate that the two sets of parallels are treated almost as two independent sets of intersecting runways. For the pure operating policy, takeoffs are cleared once a landing passes the intersection, and occur in such a way that the two mile departure/arrival separation does not limit operations. In this operating situation the "without interference" policy more closely describes the actual situation and therefore is indeed the more appropriate policy choice for comparison purposes.

The exercises described above have incorporated some preliminary investigation of model throughput sensitivity to aircraft mix and to runway operating policy. Throughput decreases, from 10 to 33 percent (averaging about 16), as the percentage of heavy aircraft in the mix increases from 5 to 50 percent. Of much greater effect on throughput are two other factors: runway operating policy, and the interference requirements. The latter are determined by ATC rules, but only apply to IFR traffic. If some crossing runways are used primarily by VFR aircraft, or if many aircraft are able to turn off before an intersection, then throughput obtained from DELCAP runs without interference rules in effect would more closely represent the actual situation. As has been noted above, care must be taken in defining the operating policy. Throughput for a mix containing 5 percent heavies for wide parallels with alternating operations on both runways is 113, while that for wide parallels handling pure operations is 78. Depending on the actual sequencing of operations on the two runways, almost any value between these two extremes can be obtained. Therefore it is necessary to be very careful in defining the operating policy to insure that the DELCAP runs model the particular situation desired, and it is strongly advisable to try a variety of policies if there is any question as to which is most applicable.

The DELCAP simulation as now constituted assumes interlanding spacings of at least 3, 4 or 5 miles as well as fixed and constant runway occupancy times, assumptions which are unrealistic. However, the validation indicates that not much additional accuracy in throughput calculations would be gained from (the very easy-to-implement step of) representing these factors in a stochastic manner.

The exercises reported in this chapter have increased our confidence in DELCAP's validity for use as a tool in setting engineered performance standards. In the cases discussed above, DELCAP's throughputs agreed very well with the theoretical values calculated, using a manual process, by the FAA's Air Traffic Service. These theoretical values are the ones with which we would expect greatest agreement, since they are arrived at,

in the simplest cases, in much the same way as DELCAP simulates events. It was hoped that the validated DELCAP would be able to take over this calculation chore, thus avoiding time-consuming and cumbersome hand operations. These validation exercises have established DELCAP's ability to handle that task. The differences between the theoretical and modified standard values highlight the fact that DELCAP (or any model, for that matter) is only a tool to aid in developing the standards. Other factors not included specifically in the model, such as airport noise restrictions, special approach or departure route requirements, ground configurations, or unusual bunching of the traffic distribution, may further limit the sustainable traffic levels, so that two facilities with the same traffic mix, configuration and operating policy may not be able to sustain the same throughput levels even though the model would output them the same. Use of model outputs without careful scrutiny is never advised in any application, but the validation results reported above indicate that the outputs of the DELCAP model will fit well into the philosophy and process already adopted by the FAA for setting engineered performance standards.

3. VALIDATION OF MODEL'S DELAY ESTIMATES

3.1 General Background

In the previous section we reported a successful effort establishing the validation of DELCAP's throughput results. This section will document an effort designed to aid in establishing the validity of DELCAP's delay outputs. Because of problems in the definition of delay and in available data, the approach reported below was unsuccessful. It is described here to provide a further example of the operation of the DELCAP model, as well as a "lesson" in how not to attempt validation of delay output.

Although the effort was unable to establish the validity of DELCAP delay output, it did illustrate how the model can be run with a mixture of scheduled traffic entered explicitly and general aviation traffic generated in a Poisson manner. Whereas model-computed delays were not comparable with actual recorded delay (measured using the difference between actual and scheduled operation times), the model-computed delay figures agree quite well with facility estimates of the delays attributable to facility operations on the day to which the data apply. In addition, the shapes of the delay curves in these two cases as they vary during the day are very similar, with peaks occurring at about the same times. This section ends with suggestions for future delay validation efforts, which would involve the collection of special data referring to that portion of delay attributable to air traffic control procedures in the the terminal areas.

Problems associated with the definitions of capacity and delay are discussed for example in [4]. Intuitively, the definition of "delay" seems clear -- to retard, to slow down, to detain -- but the crux of the problem lies in the question -- retard, slow down, detain relative to what? Presumably there is a faster way to accomplish the activity in question, and delay is experienced because of not being able to do it that way. The commercial air passenger believes he is delayed only if he arrives later than his scheduled arrival time. The pilot may perceive delay whenever he has to wait in a queue on the ground or in a holding pattern. The ATC system seeks to measure ATC delays, those resulting from ATC procedures, but unfortunately it is difficult to separate them from those resulting from schedule bunching. The ATC system does not count those delays occurring on the ground because of airline procedures, including those resulting from gate assignment problems or from crew or equipment shortages. Path stretching procedures are not normally considered by the ATC system to generate "delay" but may be so considered by others.

Thus each party of the air transport system has a different part of the total delay in mind when speaking of delay. The approach to delay calculation also matters, since whether delay occurs only during specific maneuvers or only because of a particular time difference (e.g. actual versus scheduled arrival times) affects the way it should be measured and calculated. The problems arising because of different definitions of delay are further complicated by the need to ascribe portions of delay to different parts of the system. ATC delay must be separated from total delay and then be apportioned to the facilities involved.

DELCAP is oriented exclusively to the effects of terminal-area ATC, and the "controls" exercised over each aircraft are necessitated predominantly by the presence of other aircraft in the environment. Therefore, the definition adopted for delay in DELCAP is the difference between the time to execute a maneuver in the presence of other aircraft and a nominal value of the time to execute that maneuver with no other aircraft involved. The DELCAP-computed delay includes only that portion of an aircraft's total delay occurring while under control of the terminal facility being modeled. It includes delay caused by airside operations, but not by ground operations, with the exception of those occurring on the runway surface. These restrictions ensure that DELCAP-computed delay refers to only that part of the ATC system, the terminal area, for which it is desired.

While this definition is a quite straightforward way to model delay, is physically meaningful, and corresponds correctly to the "terminal-area ATC" level of analysis for which DELCAP was commissioned, it does not correspond to any current operational definition. Thus, in order to validate DELCAP's delay figures it will be necessary to mount a special data collection effort. The characteristics of such an effort are described below in section 3.6.

It was recognized early in the DELCAP-delay validation work (and indeed noted earlier when describing future work in [1]) that there would be difficulties in comparing the data on delay available from the scheduled and actual operation times with the delays measured by DELCAP. Despite these anticipated problems, it was decided jointly with the FAA to continue on and to learn as much as possible using these data, which were the only ones available in time without a special data collection effort. Even if the analysis of delay output showed inconsistencies, the exercise would allow testing DELCAP in a mode discussed previously but not actually run: mixing scheduled and stochastic types of traffic input.

In the past, DELCAP has been run on a variety of runway configurations representing several of the nation's busiest airports, but each of these efforts used traffic descriptions concocted from general knowledge of the traffic levels expected at the facility. The exercise described below uses actual traffic for LaGuardia Airport (LGA) for Friday, October 25, 1974. The facility reported good weather conditions that day and "no delays" (i.e. no aircraft delayed more than 15 minutes). This includes only delays occurring while aircraft are in a holding pattern or a ground departure queue. Other factors contributing to passenger-experienced longer trips, such as path-stretching, alternate routing, airline gate delays, or equipment problems, are not included in such estimates. Some of these factors, in particular path-stretching, do contribute to the DELCAP-computed delay figures. The LGA facility reports only delays occurring while the arriving or departing aircraft are under its control, specifically while they are in the facility's holding pattern or queues.

LGA handled 939 operations, of which 715 were air carrier operations and the rest were mainly general aviation, with a few non-scheduled suburban carriers included. The runway configuration for LGA is depicted in Figure 3.1.

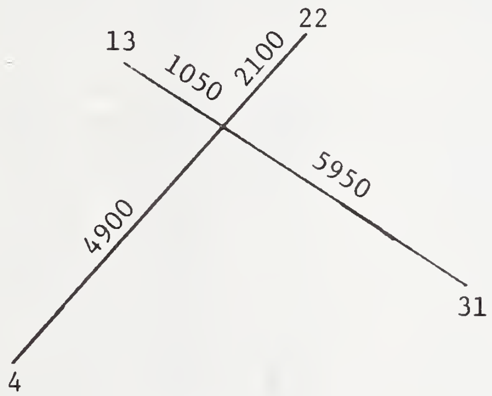

FIGURE 3.1

Runway Configuration for LGA

Most of the time the airport is operated with landings on one of the runways and takeoffs on the other, with runway-directions depending on wind direction. A more detailed description of the input data for the DELCAP run of LGA is given below.

3.2 Traffic Input Data

Traffic data for LGA are available from two sources: scheduled operations from the Official Airline Guide [3] and actual operations from CATER* data. The Airline Guide schedule data were provided to us by the FAA from a printout of the FAA's Airport Information Retrieval System (AIRS) program, which extracted the data in a form convenient to use in this effort. A sample of this data appears in Figure 3.2. Arrivals and departures were listed separately, sorted by departure or arrival time. Ten minutes had been subtracted from arrival time (added to departure time) to allow for the difference between gate time and touchdown (start-of-roll). The data include the flight identification, the operation time (touchdown or start-of-roll), the aircraft type, and additional data giving origi-

*CATER, Collection and Analysis of Terminal Records, has been instituted at the three large New York airports (LaGuardia, Kennedy and Newark), and under it data are relayed to Washington concerning each operation at any of the airports as well as meteorological conditions.

FIGURE 3.2

Sample Schedule Data

1400 A/C 20 G/A 4

DL01905	1400	TEH7	010[illegible]	ZBW
AA00564	1405	J72S	0056	ZOB
SO00710	1409	JDC9	0041	ZDC
NA00 92	1417	J727	0217	ZMA
FA00892	1424	J72S	0224	ZMA
NW002[illegible]	1424	J727	0139	ZAU
TW00310	1427	J727	0142	ZAU
AA00442	1438	J72S	0103	
NW002[illegible]0	1440	J727	0210	ZMP
AA00272	1443	J72S	0158	ZKC
AA00412	1443	J727	0143	ZAU
FA0103<	1443	JD9S	0043	ZBW
TW00570	1445	JDC9	005[illegible]	ZOB
PI00[illegible]72	1447	J737	0049	ZDC
TW00072	1450	J72S	020[illegible]	ZKC
NC0005	1450	JD9S	0140	ZAU
FA0243<	1450	JD9S	0050	ZDC
FA0015[illegible]	1451	J727	0148	ZJX
AL00492	1455	JB11	0055	ZOB
UA00840	1459	J737	0109	ZOB

1500 A/C 21 G/A 4

AA00298	1505	J727	0108	ZOB
AA00142	1505	J727	0035	ZDC
UA00450	1517	J727	021[illegible]	ZMP
AA002[illegible]1	1518	J72S	0048	ZDC
AA00606	152[illegible]	J72S	0141	ZME
DL00709	152[illegible]	JD9S	0026	ZBW
NA00144	1523	JD10	0213	ZMA
TW00314	1529	J72S	0144	ZAU
UA00904	153[illegible]	J72S	0145	ZAU
FA0 163	1538	J727	0053	
FA01[illegible]4<	1540	JD9S	004[illegible]	ZBW
[illegible]	154[illegible]	J727	0115	ZOB
CZ00906	154[illegible]	JD9S	0042	ZDC
TW0[illegible]124	1546	J727	01[illegible]	ZID
AL00621	1547	TCV5	0042	ZDC
AA00302	1548	J72S	0148	ZAU
FA00740	1550	JD9S	0220	ZMA
FA0[illegible]102	1550	JD9S	0151	ZTL
FA0244<	1550	JD9S	0050	ZDC
NA00428	1550	J72S	0045	ZDC
FA0[illegible] 60	1559	J727	0226	ZHU

nating (or terminating) air route control center and flight time. Flight ID's with the symbol < as final character belong to Eastern Airline's shuttle flights and may represent several actual aircraft for each flight because of extra sections. Aircraft types represented in the example in Figure 3.2 include Fokker Friendship Turbo-prop F-227 (TFH7), Boeing 727 and Stretch 727 (J727 and J72S), Douglas DC9 and Stretch DC9 (JDC9 and JD9S), Boeing 737 (J737), BAC 111 (JB11), Douglas DC10 (JD10), and the Convair 580 Turbo-prop (TCJ5). All of these, with the exception of the DC10 (a heavy aircraft), are "category 3" aircraft types.

A sample of the CATER data on actual flight operations at LGA appears in Figure 3.3. These data are taken from flight strips and transmitted daily via teletype from New York to Washington. Touchdown and start-of-roll times are recorded for all operations at the three New York airports (LGA), JFK and EWR). Data recorded include the date and time of each operation, the flight identification, the aircraft type, the user category (Air carrier, General aviation, or Suburban), arrival or departure designator, IFR or VFR distinction, the runway on which the operation occurred, and gate departure time for takeoffs. In addition to these traffic data, the CATER printout also indicates operating policy and changes in policy as well as weather conditions (primarily visibility range and wind direction and speed). The traffic recorded in the CATER data includes helicopter operations, designated by aircraft type HELO and an H associated with the user type (AH is air carrier helicopter, for example), but only fixed-wing operations were included in the simulation input.

Input from the two sources, scheduled operations and actual operations, was matched and discrepancies noted. The discrepancies and efforts to reconcile them are discussed in greater detail in Appendix F, which also contains a listing of the actual traffic input to the model.

3.3 Delay Analysis of the Input Data

For each of the 702 flights for which the data contained both a scheduled operation (landing or takeoff) time and an actual operation time, "delay" was computed as the difference between the two times. Figure 3.4 records for each hour the number of aircraft whose delay fell into each delay category (5-minute intervals ranging from no-delay to over one hour's delay). In addition to the hourly delay profile for all aircraft, Figure 3.4 also contains separate profiles for landings and takeoffs. In each case 26-27 precent of all operations are delayed more than 30 minutes and 8-9 percent are delayed over an hour. Since the facility reported good weather with "no delays", these long delays must be the result of problems occuring elsewhere in the air traffic control system. This indicates the difficulties, to be described below, in attempting to use this delay profile for validating DELCAP-computed delays. DELCAP models only the LGA terminal area, and can thus estimate only that subtotal within the total delay which occurs within that terminal area. The delays reported in Figure 3.4, representing the difference between the actual and scheduled operation times, include many delay factors not attributable to conditions in the LGA terminal area. Even departures from LGA can be delayed by late arrival of equipment from elsewhere.

FIGURE 3.3

Sample of Actual Traffic Data

LGA DAILY

DATE 10/25/74 LIST OF OPERATIONS PAGE 07

DTG/OP FLT/ID	A/C	CT	AD	IV	RNY	DTR	REMARKS/WEATHER/COMMENTS
•••••• ••••••	•••	••	••	••	•••	••••	••••••••••••••••••••••••
251442-EA153	DC9	A	D	I	13	1437	
251444-PI4	B737	A	A	I	22		
251444-AA593	B727	A	D	I	13	1433	
251446-AA442	B727	A	A	I	22		
251447-NY1	HELO	AH	D	V	///		
251448-TW570	DC9	A	A	I	22		
251450-EA1031	DC9	A	A	I	22		
251452-EA892	B727	A	A	I	22		
251453-AA272	B727	A	A	I	22		
251453-EA543	DC9	A	D	I	13	1449	
251455-NC50	DC9	A	A	I	22		
251455-AA389	B727	A	D	I	13	1450	
251456-NW200	B727	A	A	I	22		
251456-N57129	AC6	G	D	I	13	1451	
251458-TW72	B727	A	A	I	22		
251458-TW323	B727	A	D	I	13	1454	
251459-AA412	B727	A	A	I	22		
251500-N503T	BA11	G	D	I	13	1455	
251500-N205L	BE55	G	A	I	22		
251502-EA1430	DC9	A	A	I	22		
251503-SO713	DC9	A	D	I	13	1457	
251504-EA150	B727	A	A	I	22		
251505-EA1441	DC9	A	D	I	13	1503	
251506-NY2	HELO	AH	A	V	///		
251506-UA840	B737	A	A	I	22		
251508-UA911	B727	A	D	I	13	1504	
251508-PI72	B737	A	A	I	22		
251510-UA469	B737	A	D	I	13	1507	
251510-AA298	B727	A	A	I	22		
251511-NY2	HELO	AH	D	V	///		
251512-N1500C	CJ23	G	A	I	22		
251513-N3253Q	C402	G	D	I	13	1505	
251513-AL492	BA11	A	A	I	22		
251515-TW115	B727	A	D	I	13	1507	
251516-AA257	B727	A	D	I	13	1511	
251516-UA450	B727	A	A	I	22		
251517-AA413	B727	A	D	I	13	1511	
251518-AA433	B727	A	D	I	13	1511	
251519-EA1040	DC9	A	D	I	13	1509	
251521-AA221	B727	A	A	I	22		
251522-N8000U	N265	G	D	I	13	1519	
251523-DL1904	F227	A	D	I	13	1520	
251526-TW314	B727	A	A	I	22		

FIGURE 3.4

Delay Profiles Using LGA Input Data

HOURLY DELAY PROFILES (SCHEDULED VERSUS ACTUAL OPERATION TIMES) LGA - 10/25/74

NUMBER OF AIRCRAFT IN EACH DELAY CATEGORY (5-MINUTE INTERVALS)

HOUR	EARLY	0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50	50-55	55-60	OVER 60	TOTAL
1	6	0	1	2	1	3	4	7	4	6	0	3	3	16	56
2	7	1	0	0	5	3	6	6	2	1	4	3	4	13	55
3	6	2	3	1	3	1	2	0	0	1	1	0	3	7	30
4	0	1	1	0	0	0	0	0	0	0	0	0	1	0	3
5	0	0	0	0	0	2	2	0	0	0	0	0	0	0	4
6	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	4	13	9	0	0	0	0	0	0	0	0	0	0	0	26
13	7	10	18	7	2	0	1	0	0	0	0	0	0	0	45
14	4	6	14	10	5	4	5	1	1	0	0	0	0	0	50
15	4	10	5	7	4	4	2	2	1	1	1	0	0	0	41
16	7	14	5	8	2	0	0	0	0	0	0	1	0	0	37
17	8	6	12	9	3	2	0	0	1	0	0	0	0	0	41
18	7	7	11	7	1	3	2	0	0	0	1	0	0	0	39
19	10	5	14	8	4	2	0	0	0	0	0	0	0	1	44
20	10	4	8	6	4	3	1	1	0	0	0	1	0	1	39
21	6	3	6	5	10	4	3	1	1	0	1	0	0	0	40
22	8	1	2	3	4	6	7	7	5	2	2	0	1	0	48
23	7	0	1	1	2	5	2	8	6	3	1	2	5	5	48
24	7	1	0	2	1	5	4	5	3	5	2	3	1	15	54
TOTAL	108	84	110	76	51	48	41	38	24	19	13	13	18	59	702

FIGURE 3.4

Delay Profiles (Cont'd)

NUMBER OF DEPARTURES IN EACH DELAY CATEGORY (5-MINUTE INTERVALS)

HOUR	EARLY	0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50	50-55	55-60	OVER 60	TOTAL
1	2	0	1	0	1	1	4	4	3	2	0	1	0	8	27
2	2	1	0	0	2	1	0	0	1	0	1	1	3	6	18
3	1	0	1	1	0	1	1	0	0	1	1	0	3	5	15
4	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	1	11	9	0	0	0	0	0	0	0	0	0	0	0	21
13	3	7	9	4	1	0	0	0	0	0	0	0	0	0	24
14	1	2	8	7	3	1	3	0	1	0	0	0	0	0	26
15	1	3	3	4	1	3	2	2	1	0	0	0	0	0	20
16	2	9	0	7	0	0	0	0	0	0	0	1	0	0	19
17	2	3	9	4	1	1	0	0	0	0	0	0	0	0	20
18	2	4	7	5	1	1	2	0	0	0	0	0	0	0	22
19	4	3	5	5	2	0	0	0	0	0	0	0	0	0	19
20	6	1	3	1	4	2	0	1	0	0	0	0	0	1	19
21	2	1	0	3	7	4	2	1	1	0	0	0	0	0	21
22	3	0	1	0	2	5	6	4	1	1	0	0	0	0	23
23	3	0	0	0	0	1	0	4	5	1	0	1	5	2	22
24	4	0	0	0	0	3	2	1	1	5	2	1	1	10	30
TOTAL	39	45	56	41	25	25	22	17	14	10	4	5	13	32	348

FIGURE 3.4

Delay Profiles (Cont'd)

NUMBER OF ARRIVALS IN EACH DELAY CATEGORY (5-MINUTE INTERVALS)

HOUR	EARLY	0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50	50-55	55-60	OVER 60	TOTAL
1	4	0	0	2	0	2	0	3	1	4	0	2	3	8	29
2	5	0	0	0	3	2	6	6	1	1	3	2	1	7	37
3	5	2	2	0	3	0	1	0	0	0	0	0	0	2	15
4	0	1	1	0	0	0	0	0	0	0	0	0	0	0	2
5	0	0	0	0	0	2	2	0	0	0	0	0	0	0	4
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	3	2	0	0	0	0	0	0	0	0	0	0	0	0	5
13	4	3	9	3	1	0	1	0	0	0	0	0	0	0	21
14	3	4	6	3	2	3	2	1	0	0	0	0	0	0	24
15	3	7	2	3	3	1	0	0	0	1	1	0	0	0	21
16	5	5	5	1	2	0	0	0	0	0	0	0	0	0	18
17	6	3	3	5	2	1	0	0	1	0	0	0	0	0	21
18	5	3	4	2	0	2	0	0	0	0	1	0	0	0	17
19	6	2	9	3	2	2	0	0	0	0	0	0	0	1	25
20	4	3	5	5	0	1	1	0	0	0	0	1	0	0	20
21	4	2	6	2	3	0	1	0	0	0	1	0	0	0	19
22	5	1	1	3	2	1	1	3	4	1	2	0	1	0	25
23	4	0	1	1	2	4	2	4	1	2	1	1	0	3	26
24	3	1	0	2	1	2	2	4	2	0	0	2	0	5	24
TOTAL	69	39	54	35	26	23	19	21	10	9	9	8	5	27	354

Long delays are reported in hours 22 to 24 and 1 to 3 (or 2100 to 300 GMT, which is 5-11 p.m. local time), with about two thirds of the departures and 52 percent of the arrivals scheduled for that period delayed more than half an hour. About 46 percent of all scheduled flights are delayed by more than 15 minutes. On the other hand about 15 percent of the operations were early: 11 percent of the departures and 20 percent of the arrivals. Since no scheduled air carrier can depart early, presumably the early departures occur in the data because of the adjustment of gate time to roll time. Since this adjustment involved a single time increment added to gate time, whereas actual taxiing time depends on gate and taxiway location, actual time may vary from the single nominal value by several minutes. This could cause an aircraft to be listed as departing early if that aircraft actually required less taxiing time than the nominal figure.

3.4 DELCAP Input

In addition to the scheduled traffic input to DELCAP shown in Appendix F, general aviation traffic was also included. Table 3.1 displays the hourly general aviation traffic levels actually maintained on October 25. Scheduled traffic was supplied to the model directly as an exogenous* input through the exogenous event routine XGEN, while a representation of general aviation traffic was generated randomly by event routine GEN according to Poisson distributions with the hourly operation rates from Table 3.1 as means. All general aviation traffic was assumed to be aircraft type 2 (light aircraft).

The runway configuration for LGA is shown in Figure 3.1. Figure 3.5 gives the preprocessor output resulting from the LGA input. "Runway 1" is runway 04, "runway 2" is runway 13, "runway 3" is runway 22, and "runway 4" is runway 31. The initial operating policy allows landings and takeoffs to alternate on runway 3 (22). Changes in policy are input exogenously through exogenous event routine CHGOP. The operating policies used during the run are given in Table 3.2. The change at 1920 -- from alternating on 3 and 2 to alternating on 3 and 4 -- involves a direction change (runway 2 to runway 4), as does the change at 0250 from 3 and 4 to 1.

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*SIMSCRIPT simulations have two ways of initiating events, exogenously and endogenously. Endogenous events are those initiated by other events in the program while exogenous events are initiated by user-supplied input data. In DELCAP, flights may be generated by either of these mechanisms: stochastically by event GEN which schedules the arrival to the system of the next flight after the previous stochastically-generated one has arrived, or externally by XGEN in which the user inputs the system arrival time of each flight and the characteristics of that flight.

TABLE 3.1

LGA General Aviation Traffic Levels By Hour

Hour	Landings	Takeoffs	Total
1	4	4	8
2	3	3	6
3	2	7	9
4	3	2	5
5	15	4	19
6	2	12	14
7	0	0	0
8	0	0	0
9	0	0	0
10	0	0	0
11	2	2	4
12	7	5	12
13	10	8	18
14	7	12	19
15	8	9	17
16	3	7	10
17	4	6	10
18	7	4	11
19	4	9	13
20	7	6	13
21	9	15	14
22	7	6	13
23	7	12	19
24	6	7	13

FIGURE 3.5

Preprocessor Output

THIS SIMULATION RUNS FROM 7.00 TO 7.00

AIRCRAFT DESCRIPTION

TYPE	SPEEDS (KNOTS) LANDING	LIFTOFF	RUNWAY OCCUPANCY (SECONDS) LANDING	TAKEOFF
1	124.	120.	55.	33.
2	119.	90.	40.	27.
3	120.	120.	50.	32.

TRAFFIC DESCRIPTION

TYPE	LANDING MIX	TAKEOFF MIX
1	0.	0.
2	100.	100.
3	0.	0.

FIGURE 3.5

Preprocessor Output (Cont'd)

AIRPORT CONFIGURATION

NUMBER OF RUNWAYS = 4

RUNWAY 1 (4) - NO POLICY PROVIDED/ NOT USED INITIALLY

RUNWAY 2 (13) - NO POLICY PROVIDED/ NOT USED INITIALLY

RUNWAY 3 (22) - DUAL USE, ALTERNATING OPERATIONS

RUNWAY 4 (31) - NO POLICY PROVIDED/ NOT USED INITIALLY

RUNWAYS 4 AND 13 INTERSECT AT A POINT 4900. FEET FROM THE
END OF RUNWAY 4 AND 1050. FEET FROM THE END OF RUNWAY 13 .

RUNWAYS 4 AND 31 INTERSECT AT A POINT 4900. FEET FROM THE
END OF RUNWAY 4 AND 5950. FEET FROM THE END OF RUNWAY 31 .

RUNWAYS 13 AND 22 INTERSECT AT A POINT 1050. FEET FROM THE
END OF RUNWAY 13 AND 2100. FEET FROM THE END OF RUNWAY 22 .

RUNWAYS 22 AND 31 INTERSECT AT A POINT 2100. FEET FROM THE
END OF RUNWAY 22 AND 5950. FEET FROM THE END OF RUNWAY 31 .

RUNWAYS 4 AND 13 ARE SEMI-DEPENDENT -
SIMULTANEOUS ARRIVALS ARE PROHIBITED

RUNWAYS 4 AND 31 ARE SEMI-DEPENDENT -
SIMULTANEOUS ARRIVALS ARE PROHIBITED

RUNWAYS 13 AND 22 ARE SEMI-DEPENDENT -
SIMULTANEOUS ARRIVALS ARE PROHIBITED

RUNWAYS 22 AND 31 ARE SEMI-DEPENDENT -
SIMULTANEOUS ARRIVALS ARE PROHIBITED

FIGURE 3.5

Preprocessor Output (Cont'd)

FRACTION OF LANDINGS OF EACH TYPE ON EACH RUNWAY

TYPE \ RUNWAY	1 (4)	2 (13)	3 (22)	4 (31)
1	.0000	.0000	1.0000	.0000
2	.0000	.0000	1.0000	.0000
3	.0000	.0000	1.0000	.0000

FRACTION OF TAKEOFFS OF EACH TYPE ON EACH RUNWAY

TYPE \ RUNWAY	1 (4)	2 (13)	3 (22)	4 (31)
1	.0000	.0000	1.0000	.0000
2	.0000	.0000	1.0000	.0000
3	.0000	.0000	1.0000	.0000

TABLE 3.2

Operating Policies for LGA, by Hour

Time	Policy
0400-1025	Alternate landings and takeoffs on runway 3(22).
1025-1920	Alternate a landing on 3(22) with a takeoff on 2(13).
1920-0250	Alternate a landing on 3(22) with a takeoff on 4(31).
0250-0400	Alternate landings and takeoffs on 1(04).

Standard aircraft-type data as shown in Figure 3.5 were used, with type 1 being heavy jets, type 2 being light aircraft, and type 3 being category 3 aircraft, i.e. medium size jets and large propeller aircraft.

3.5 DELCAP Output

Summary output from the DELCAP run of the LGA data is shown in Figure 3.6. Since the general aviation traffic was entered stochastically, it is not surprising that the DELCAP traffic total (934) is slightly lower, by about 0.5%, than the actual total (939). Each average hourly throughput figure is obtained by dividing total throughput for that runway and operation type by the time within the hour during which the runway accepts that operation. If the time period is not a busy one or if it includes a long time during which no operations occur, the average hourly throughput may differ greatly from that for a typical hour with more traffic. The average hourly delay is computed similarly, by dividing the sum of the delays suffered by all aircraft of the appropriate operation type on the runway in question by the time period over which that runway accepts that operation. The delay is thus the hourly average of all the aircraft delays for aircraft that landed (or started to roll) in the time period in question. (Delay is recorded at touchdown or start of roll, so that a delay which actually occurred before a change of policy may be recorded after the change.)

The DELCAP delay profile is given in Figure 3.7. This also is standard DELCAP output whenever the delay output option is selected. Only 66 aircraft, about 7 percent of all operations, had delays of more than fifteen minutes, which agrees fairly well with the facility estimate of "no delay" (since the facility records only delays of more than fifteen minutes). Over half of all operations (57 percent) suffered less than 5 minutes delay. Peak delays occurred during hours 15 (10-11 a.m.) and 22 (5-6 p.m.), which agrees well with the peak traffic hours of 14 and 23. Regarding LGA as it is operated during busy periods as a pair of V-shaped intersecting runways, operated with landings on one and takeoffs on the other, the capacity of the airport should be about 75 operations per hour (from Table 2.5). Thus the highest traffic input (69 operations in an hour) is less than the airport capacity, but some delay results nonetheless, since the times at which aircraft desire service are bunched instead of being evenly spaced. For instance, 42 percent (8 out of 22) of the departures in hour 1 are scheduled to depart at exactly 0000, clearly a situation making delay inevitable. Arrivals to the terminal area are not as bunched as departures, and even when several have the same scheduled arrival time, their prior processing by the air traffic control system tends to space them apart more than the schedule would indicate. This may explain in part why average takeoff delay per aircraft in Figure 3.6 is greater than the average landing delay, even when the number of landings exceeds the number of takeoffs.

FIGURE 3.6

DELCAP Summary Output

HOUR	RUNWAY	HOURLY THROUGHPUT LANDINGS	TAKEOFFS	TOTAL	HOURLY DELAY PER AIRCRAFT LANDINGS	TAKEOFFS	ALL
8	1	0	0	0	0.	0.	0.
	2	0	0	0	0.	0.	0.
	3	0	0	0	0.	0.	0.
	4	0	0	0	0.	0.	0.
9	1	0	0	0	0.	0.	0.
	2	0	0	0	0.	0.	0.
	3	0	0	0	0.	0.	0.
	4	0	0	0	0.	0.	0.
10	1	0	0	0	0.	0.	0.
	2	0	0	0	0.	0.	0.
	3	0	0	0	0.	0.	0.
	4	0	0	0	0.	0.	0.
11	1	0	0	0	0.	0.	0.
	2	0	2	2	0.	0.	0.
	3	1	0	1	0.	0.	0.
	4	0	0	0	0.	0.	0.
12	1	0	0	0	0.	0.	0.
	2	0	29	29	0.	5.4	5.4
	3	14	0	14	0.3	0.	0.3
	4	0	0	0	0.	0.	0.
13	1	0	0	0	0.	0.	0.
	2	0	33	33	0.	4.6	4.6
	3	31	0	31	5.0	0.	5.0
	4	0	0	0	0.	0.	0.
14	1	0	0	0	0.	0.	0.
	2	0	37	37	0.	11.8	11.8
	3	35	0	35	4.5	0.	4.5
	4	0	0	0	0.	0.	0.
15	1	0	0	0	0.	0.	0.
	2	0	35	35	0.	12.0	12.0
	3	23	0	23	1.8	0.	1.8
	4	0	0	0	0.	0.	0.
16	1	0	0	0	0.	0.	0.
	2	0	23	23	0.	2.9	2.9
	3	21	0	21	3.3	0.	3.3
	4	0	0	0	0.	0.	0.
17	1	0	0	0	0.	0.	0.
	2	0	30	30	0.	3.0	3.0
	3	24	0	24	2.4	0.	2.4
	4	0	0	0	0.	0.	0.
18	1	0	0	0	0.	0.	0.
	2	0	26	26	0.	2.6	2.6
	3	27	0	27	1.7	0.	1.7
	4	0	0	0	0.	0.	0.
19	1	0	0	0	0.	0.	0.
	2	0	21	21	0.	1.4	1.4
	3	21	0	21	3.5	0.	3.5
	4	0	0	0	0.	0.	0.

FIGURE 3.6 .

DELCAP Summary Output (Cont'd)

20	1	0	0	0	0.	0.	0.
	2	0	15	15	0.	2.5	2.5
	3	31	0	31	5.6	0.	5.6
	4	0	14	14	0.	12.7	12.7
21	1	0	0	0	0.	0.	0.
	2	0	0	0	0.	0.	0.
	3	31	0	31	6.4	0.	6.4
	4	0	37	37	0.	13.5	13.5
22	1	0	0	0	0.	0.	0.
	2	0	0	0	0.	0.	0.
	3	38	0	38	9.1	0.	9.1
	4	0	38	38	0.	17.9	17.9
23	1	0	0	0	0.	0.	0.
	2	0	0	0	0.	0.	0.
	3	35	0	35	2.9	0.	2.9
	4	0	36	36	0.	9.2	9.2
0	1	0	0	0	0.	0.	0.
	2	0	0	0	0.	0.	0.
	3	30	0	30	2.5	0.	2.5
	4	0	32	32	0.	5.0	5.0
1	1	0	0	0	0.	0.	0.
	2	0	0	0	0.	0.	0.
	3	37	0	37	5.4	0.	5.4
	4	0	28	28	0.	6.1	6.1
2	1	0	0	0	0.	0.	0.
	2	0	0	0	0.	0.	0.
	3	23	0	23	1.2	0.	1.2
	4	0	18	18	0.	7.0	7.0
3	1	0	0	0	0.	0.	0.
	2	0	0	0	0.	0.	0.
	3	11	0	11	0.0	0.	0.0
	4	0	9	9	0.	2.9	2.9
4	1	5	2	7	0.1	0.	0.1
	2	0	0	0	0.	0.	0.
	3	0	0	0	0.	0.	0.
	4	0	0	0	0.	0.	0.
5	1	1	0	1	0.	0.	0.
	2	0	0	0	0.	0.	0.
	3	18	1	19	0.8	0.	0.8
	4	0	0	0	0.	0.	0.
6	1	0	0	0	0.	0.	0.
	2	0	0	0	0.	0.	0.
	3	3	7	10	0.	0.1	0.1
	4	0	0	0	0.	0.	0.
7	1	0	0	0	0.	0.	0.
	2	0	0	0	0.	0.	0.
	3	0	1	1	0.	0.	0.
	4	0	0	0	0.	0.	0.

FINAL RANDOM NUMBER SEED 302305135602

FIGURE 3.6

DELCAP Summary Output (Cont'd)

SUMMARY REPORT FOR THIS RUN

TOTAL THROUGHPUT

RUNWAY	OPERATIONS PERFORMED LANDINGS	TAKEOFFS	TOTAL
1	6	2	8
2	0	251	251
3	454	9	463
4	0	212	212
TOTAL	460	474	934

AVERAGE HOURLY THROUGHPUT

RUNWAY	OPERATIONS PERFORMED LANDINGS	TAKEOFFS	TOTAL
1	0.2	0.1	0.3
2	0.	10.5	10.5
3	18.9	0.4	19.3
4	0.	8.8	8.8
TOTAL	19.2	19.7	38.9

AVERAGE HOURLY DELAY

RUNWAY	DELAY (MINUTES) LANDINGS	TAKEOFFS	TOTAL
1	0.0	0.	0.0
2	0.	60.6	60.6
3	72.6	0.0	72.6
4	0.	90.4	90.4
TOTAL	72.6	151.0	223.6

FIGURE 3.7

DELCAP Delay Profile

DELAY PROFILE - NUMBER OF AIRCRAFT IN EACH DELAY CATEGORY BY HOUR

MINUTES DELAYED

HOUR	NO DELAY	05-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50	50-55	55-60	OVER 60
1	40	8	16	1	0	0	0	0	0	0	0	0	0
2	26	13	2	0	0	0	0	0	0	0	0	0	0
3	19	1	0	0	0	0	0	0	0	0	0	0	0
4	7	0	0	0	0	0	0	0	0	0	0	0	0
5	20	0	0	0	0	0	0	0	0	0	0	0	0
6	10	0	0	0	0	0	0	0	0	0	0	0	0
7	1	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0
11	3	0	0	0	0	0	0	0	0	0	0	0	0
12	31	7	5	0	0	0	0	0	0	0	0	0	0
13	36	20	3	0	0	0	0	0	0	0	0	0	0
14	22	21	25	4	0	0	0	0	0	0	0	0	0
15	25	10	11	9	3	0	0	0	0	0	0	0	0
16	31	13	0	0	0	0	0	0	0	0	0	0	0
17	43	10	1	0	0	0	0	0	0	0	0	0	0
18	48	4	1	0	0	0	0	0	0	0	0	0	0
19	36	5	1	0	0	0	0	0	0	0	0	0	0
20	30	13	12	5	0	0	0	0	0	0	0	0	0
21	11	15	31	11	0	0	0	0	0	0	0	0	0
22	8	13	25	19	8	4	0	0	0	0	0	0	0
23	40	13	15	3	0	0	0	0	0	0	0	0	0
24	45	14	3	0	0	0	0	0	0	0	0	0	0
TOTAL	532	180	156	51	11	4	0	0	0	0	0	0	0

Table 3.3 gives a detailed trace of the various events in the operation of several aircraft. During this time period, landings on runway 3(22) were alternated with takeoffs on runway 2(13) whenever possible. An option in the DELCAP model has been developed which prints out the times of various events in a slightly different format, arranged by time of occurrence rather than flight, and with an internal flight identification number instead of the actual flight number. In Table 3.3 we have arbitrarily assigned the general aviation flights tail numbers N0001 to N0005 for convenience. Figure 3.8 displays the same output (with two additional flights at the end) directly as it comes from the computer. It should be noted that in the computer output flight identification numbers may be repeated after an aircraft lands or takes off, although at any one time the number refers to only one aircraft.* Examples are flight ID's 18199 and 18203 in Figure 3.8. It will also be noted that because of roundoff procedures the times at which flights enter the simulation may be printed, as for instance, 15.09.59 rather than 15.10.00.

These detailed printouts can be used to aid in evaluating the delays given by the DELCAP delay profile as well as to ascertain how the model actually treats the various operations. Such analysis of the internal procedures of the model is itself a valuable step in establishing model validation.

One comparison of the distribution of "total delay" as actually occurring (from Figure 3.4) with DELCAP-computed delay (from Figure 3.7) is given graphically in Figure 3.9, which shows the cumulative frequency distribution for the two sets of "delay" figures. Only a quarter of actual operations experience either no delay or delays of less than 5 minutes, while well over half (57 percent) of the simulated operations fall into this category. All simulated aircraft experience less than 25 minutes delay while only 68 percent of the actual operations do so. Thus there is very little agreement between simulated and actual delays.

This discrepancy can mean one of two things: either the model does not correctly model delay and is erroneous, or else the data are inappropriate for this particular analysis. Even before the simulation was run, analysis of the input data delay profile in Figure 3.4 indicated difficulties in using the actual versus schedule operation time data as a basis for terminal delay estimates. The LGA tower facility had reported "no delays" on a day in which over one quarter of the operations were actually delayed more than half an hour, with 8 to 9 percent delayed more than an hour. Clearly this is possible only if the delays occurred elsewhere. The 59 operations delayed over an hour would certainly have complained about incurring such delays at a facility having no problems with runways, weather or unusually high traffic levels, lending further credibility to the supposition that most of this delay did not occur at LGA.

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*This is done for efficient computer storage of flight information.

TABLE 3.3

Example of the Detailed Trace of Simulated Operations

FLT ID	RW	TYPE	TIME ENTERS	LANDING TIMES			TAKEOFF TIMES	
				OUTER MARKER	TOUCHDOWN	TURNOFF	ROLL	LIFTOFF
N0001	3	2	1508.11*	1512.30	1515.22	1516.02	--	--
UA0450	3	3	1510.00	1518.14	1521.05	1521.55	--	--
AA0221	3	3	1511.00	1519.44	1522.35	1523.25	--	--
DL1904	2	3	1512.00	--	--		1519.49	1520.21
N0002	3	2	1512.45	1521.15	1524.07	1524.47	--	--
AA0606	3	3	1515.00	1526.30	1529.21	1530.11	--	--
DL0709	3	3	1515.00	1528.00	1530.51	1531.41	--	--
N0003	3	2	1517.38	1529.31	1532.23	1533.03	--	--
N0004	2	2	1520.13	--	--	--	1528.03	1528.30
N0005	2	2	1520.42	--	--	--	1529.32	1529.59
AA442	2	3	1522.00	--	--	--	1531.02	1531.34
TW0314	3	3	1522.00	1531.02	1533.53	1534.43	--	--

*Time appears as hour, minutes and seconds, so that, for example, 1508.11 is 8 minutes and 11 seconds after 1500 hours.

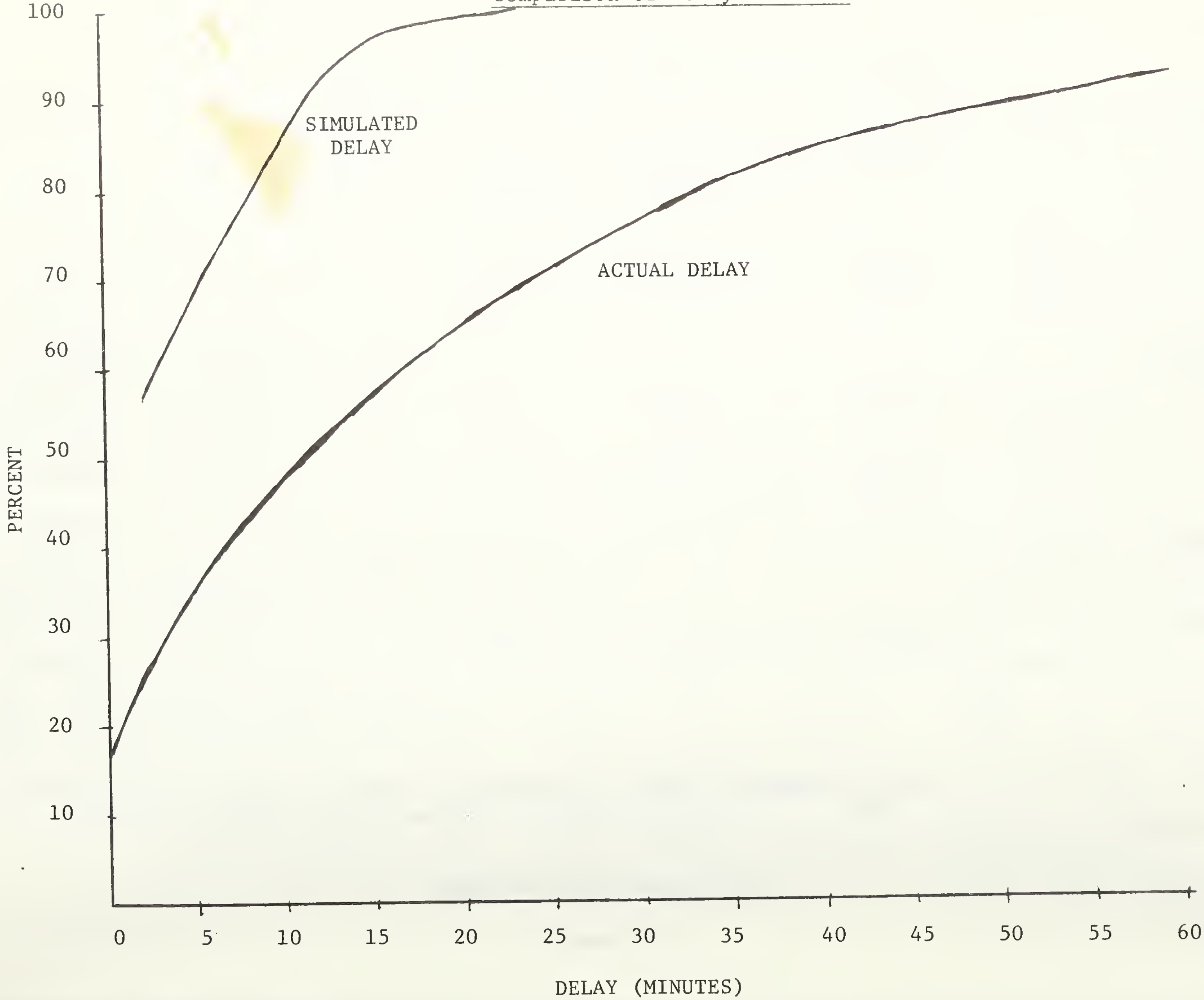
FIGURE 3.8

Computer Output: Detailed Trace

ENTERS SIMULATION						LANDING					TAKEOFF			
IN/EX	FLT	RW	TIME	OP	TY	FLT	RW	OM	TOUCHD	OFF	FLT	RW	ROLL	LIFTOFF
GA	18199	3	15.08.11	2	2									
AC	17971	3	15.09.59	2	3									
AC	17967	3	15.10.59	2	3									
AC	18203	2	15.11.59	1	3									
						18199	3	15.12.30	15.15.22	15.16.02				
GA	17827	3	15.12.45	2	2									
AC	18199	3	15.15.00	2	3									
AC	18039	3	15.15.00	2	3									
											18203	2	15.19.49	15.20.21
GA	18203	3	15.17.38	2	2									
						17971	3	15.18.14	15.21.05	15.21.55				
						17967	3	15.19.44	15.22.35	15.23.25				
GA	18195	2	15.20.13	1	2									
GA	18043	2	15.20.42	1	2									
						17827	3	15.21.15	15.24.07	15.24.47				
AC	17875	2	15.21.59	1	3									
AC	17983	3	15.21.59	2	3									
AC	18075	2	15.21.59	1	3									
AC	17879	2	15.21.59	1	3									
											18195	2	15.28.03	15.28.31
						18199	3	15.26.30	15.29.21	15.30.11				
											18043	2	15.29.32	15.29.59
						18039	3	15.28.00	15.30.51	15.31.41				
											17875	2	15.31.02	15.31.34
						18203	3	15.29.31	15.32.23	15.33.03				
											18075	2	15.32.35	15.33.07
						17983	3	15.31.02	15.33.53	15.34.43				
											17879	2	15.34.05	15.34.37

FIGURE 3.9

Comparison of Delay Profiles



The long delays occur late in the day and landing delay peaks before takeoff delay, leading one to speculate that the takeoff delays are caused in part by delayed arrivals of an aircraft needed for a later departure. Arrival delay, computed as scheduled minus actual arrival time, clearly includes all delays occurring during the whole flight, whether caused by air traffic control (ATC) factors or something else (equipment malfunction, for example). Takeoff delay will not contain ATC delays from other sectors for this flight, but may be affected by delays to an earlier flight using the same aircraft, and may also include (non-ATC) delays due to equipment, crew and gate problems. Thus even before the simulation was run, there was doubt as to the likelihood of any agreement of the actual delays with the simulation output delays, which represent ATC delays only in the LGA terminal area. Once the simulation output became available, these fears were realized as displayed in Figure 3.9.

Although the delay profiles were quite different, their "shapes" appear similar; that is, as delay varies over the day the actual and the DELCAP-computed delays peak or fall at the same times. To test this hypothesis, i.e. that the distributions have the same general shape, the number of flights actually delayed excessively in each hour are compared in Table 3.4 with the corresponding number of flights with excessive model-computed delays. For the actual delay data excessive delay is taken to mean more than 15 minutes; for the simulated flights delays of 5 minutes or more were considered excessive since few flights were delayed in DELCAP by more than 15 minutes. Observations in the two columns were ranked separately, and these rankings compared by hour using the Spearman rank correlation coefficient,* whose value was .725, significant at the .001 level. This means that the probability of getting such agreement of two rankings by chance alone is less than .001. Clearly some correlation between the two distributions is to be expected since they both depend on the same traffic input, but the level of significance is high enough to indicate greater agreement than one would expect from this fact alone.

Although, as the discussion above indicates, the LGA exercise has shown the inadequacy of the particular data base used, it has been included in this report because that type of data base is the one most often suggested for delay validation and the one most obvious to those not directly involved in modeling. Elucidation of the problems associated with this approach will perhaps aid others involved in similar efforts by providing a concrete example of the difficulties. Since the "scheduled versus actual operation time" data base is inadequate to validate the DELCAP delay calculations, we will include below a description of a data base, together with directions for its collection, which we believe would

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*For a further explanation of this statistic and its use see Sidney Siegel, Nonparametric Statistics for the Behavioral Sciences, McGraw-Hill, New York, 1956, pp. 202-213.

TABLE 3.4

Number of Flights Delayed Excessively in Each Hour

HOUR	NUMBER ACTUALLY DELAYED	NUMBER DELAYED IN DELCAP
1	47	25
2	47	20
3	18	1
4	1	0
5	4	0
6	1	0
7	0	0
8	1	0
9	0	0
10	0	0
11	0	0
12	0	12
13	3	28
14	16	50
15	15	33
16	3	13
17	6	11
18	7	5
19	7	6
20	11	30
21	20	57
22	34	68
23	37	31
24	44	17

be adequate for that task. The internal trace output can be used to better understand the internal operation of DELCAP, and thus acts as a beginning delay validation, but in the absence of the type of data base described below the validity of delays calculated by DELCAP is not yet demonstrated. It should be remembered, however, that DELCAP throughput output has been validated for use in setting engineered performance standards by the exercises reported above in Section 2.

3.6 Data Required for DELCAP Delay Validation

The delay measured by the DELCAP model includes (as intended) only that delay incurred by an aircraft in the terminal area being modeled, and incurred because of separations required between aircraft. The delay is calculated as the difference between the minimum time for an aircraft to execute the maneuver in question (fly from handoff to the outer marker, make its final approach, land, and exit the runway -- or request clearance, exit from the gate, taxi to the departure runway, start its roll and liftoff) and the time it actually takes in the presence of other aircraft.

Instead of scheduled arrival and departure times, the model needs actual handoff and departure-request times. Using these will overcome the problem of including delays occurring elsewhere, by capturing just that portion of a flight arising within the terminal area in question. The actual handoff times will spread out the arrivals from the artificially bunched scheduled arrival times, thus reflecting the effect of the ATC system in smoothing out schedule bunching. The use of gate-departure request time will avoid contaminating the analysis with the results of late equipment arrivals, equipment problems and other non-ATC-caused delay factors causing late departure requests.

The actual handoff and gate request times could be obtained by stationing people in the tower and monitoring the appropriate positions, recording the times and flight numbers. It would also be necessary to record actual touchdown and start-of-roll times for each flight. These data could be obtained in a similar manner from the tower in good weather, if the tower is situated so that the runway is visible. Monitoring the appropriate approach or departure position would provide the flight ID, but visual recording of touchdown and start-of-roll time would be required. These data could in principle be obtained as part of some other airport data collection effort.

Such data would allow an analysis of terminal-area ATC-specific delays, and comparison of the delays output by the model with actual delay of the type the outputs are supposed to represent. (However, one major risk of discrepancy remains. Path-stretching procedures may be used by facilities without the additional flying time contributing to facility-computed delay, while that time would contribute to DELCAP-calculated delays. We emphasize again the necessity for comparisons based on the same definition and measure of "delay".)

The analysis would focus on the comparison of DELCAP delays with delays calculated as the difference between the actual operation time (handoff to touchdown, or departure-request to roll) and a minimum time for that operation. Ideally, this input data set would allow a flight-by-flight comparison (using DELCAP's detailed trace procedure) of actual and simulated events. In addition, comparison of delay profiles could be used to assess overall performance. It is this latter that is most critical for future application of the model, and discrepancies in individual flight behavior are less important than is absence of overall bias or other systematic errors.

If DELCAP-computed delays are to be used in further analyses of the ATC system, there seems no choice but to evaluate these delay outputs using data obtained in the manner outlined above. Such a procedure is not necessary for further use of the model's throughput values, since the exercises reported in Section 2 have demonstrated the validity of that output for use in the engineered performance standard program.

4. CONCLUSIONS

The DELCAP simulation model is an existing analysis tool which has proven useful in aiding the setting of engineered performance standards. It has been operated both on the UNIVAC 1108 at NBS and on a CDC computer chosen by the FAA, and has been run both by its designers at NBS and by FAA personnel.

We have reported in Section 2 the results of a validation of DELCAP-produced throughput levels for use in FAA's EPS program. This analysis included an examination of DELCAP outputs for five different configurations (a single runway, two pairs of intersecting runways with different placements of the intersection, a pair of close parallel runways, and close parallels with a crossing runway) representative of the configurations most commonly found at major terminals*, and for three or four operating policies for each configuration. The tests included three arrival/departure mixes, and the operating policies were chosen to apply to the appropriate mixes. Each configuration and policy was run on each of three different aircraft-type mixes, distinguished primarily by the fraction of heavy aircraft in the mix and ranging from 5 percent to 50 percent heavies. Comparison of the model results with FAA-computed values at 5 airports, covering 7 configuration/policy combinations, was carried out. The DELCAP values were within 5 to 6 percent of the FAA-computed values in all cases but one, and were within 10 percent in that case. Thus the DELCAP model has been accepted as a good substitute for the manual procedure developed by the FAA, and because of its ease of use and flexibility, it can extend and enhance the FAA's analyses in the program.

The LGA exercise reported in Section 3 demonstrated the model's ability to simulate actual scheduled traffic together with randomly generated general aviation traffic and to measure delays from these operations. Inasmuch as the data presently available are insufficient to isolate delay occurring in the portion of the ATC system DELCAP was designed to model, we are unable to validate DELCAP's delay outputs without a further data collection effort. Such an effort, involving collection in a terminal area of handoff and request-to-depart times as well as actual operation times, is described in Section 3. The "delay validation" exercise has highlighted the importance of insuring that definitions of delay are the same, since there are many different definitions of this complex concept. Although DELCAP's delay values could not be validated because of these data problems, model output agreed well with facility estimations of delay and the time distributions of delay (actual versus DELCAP) were similar. These results give a preliminary indication that DELCAP-computed delays may indeed be useful for analyses, an indication which can only be checked by further efforts.

The exercises reported in Section 2 indicate that the DELCAP model is most sensitive to operating policies. Since different operating policies are optimal for different arrival/departure ratios, this factor also greatly affects model output. The model is also quite sensitive to runway

*We note again that wide parallels are effectively two independent single runways.

configuration, particularly to the number and the independence (or interdependence) of the runways, but the location of an intersection and the difference between close parallels and an intersecting pair of runways have only minor effect on throughput. Aircraft-type mix has less effect on throughput than do operating policy and major configuration differences, but it is still an important factor. Separations, too, have an effect on the throughput, but reduction of all separations to three miles or less (for a dual-use single runway) has less effect than one might expect. (Despite the reduction in minimum inter-landing separation, landing aircraft must be separated by more than three miles in order for takeoffs to occur between landings.) Other factors affecting sensitivity include approach speeds and runway occupancy times, but for the ranges occurring at the busier airports, the model is less sensitive to these than to the other factors given above.

DELCAP is a tool whose usefulness and validity have been demonstrated for application in the Engineered Performance Standards Program. It may also be useful for other analyses, but care should be exercised that the model is appropriate and that the validations like those described in this report be performed and include the types of scenarios to be represented for that application. In order to use the delay figures output by DELCAP, further validation -- requiring a special data collection effort such as that suggested in Section 3.6 -- will be necessary. Preliminary indications from the LGA exercise reported above, suggest that such an effort would be successful.

5. REFERENCES

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2. Judith F. Gilsinn, Validation of Maximum Airport Throughput Levels Estimated by the DELCAP Simulation Model, NBS Report Number NBS-IR 75-638, FAA Report Number FAA-RD 75-66, January 1975.

3. Official Airline Guide, North American Edition, Reuben H. Donnelly Corporation, Oak Brook, Illinois 60521.

4. Analysis of a Capacity Concept for Runway and Final-Approach Path Airspace, NBS Report Number 10111, FAA Report Number RD-69-47, November 1969.

5. A.J. Goldman and W.A. Steele with W.A. Horn, Continued Analysis of a Capacity Concept for Runway and Final-Approach Path Airspace, NBS Report Number 10589, April 1971.

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8. A. Blumstein, The Operations Capacity of a Runway used for Landings and Takeoffs, in Proc. Second Inter. Conf. on Operational Research, J. Banbury and J. Maitland (ed.), John Wiley and Sons, pp. 657-672, 1961.

9. R.M. Harris, Models for Runway Capacity Analysis, MITRE Corporation Technical Report Number MTR 4102, October 1969.

APPENDIX A

CHANGES AND ADDITIONS TO DELCAP

During the course of the validation effort reported in this document, modifications were made to DELCAP and its preprocessor in several areas: output, separation criteria, random number generator, operating policies, changes in operating policy, and standard preprocessor inputs. Several criteria were used in deciding which of a number of plausible changes should be implemented, and first among these was the preservation of the DELCAP design philosophy, that the model should remain easy and inexpensive to operate. A second factor was the benefit expected to accrue and the priority of need for that change in the Engineered Performance Standards Program. The changes chosen for implementation are described below.

A.1 Modifications in Output

DELCAP is expected to operate under two scenarios: one to compute airport maximum throughput (capacity) and the second to compute delay resulting from a particular demand profile. Since delay output would be meaningless under the first scenario, the user now has the option of suppressing delay output for runs under this scenario. Current output formats have been modified so that the number of characters per line is less than 72, permitting output to fit on most terminals. Output now consists of actual throughputs and average delay per aircraft for each hour, separately for landings, takeoffs and total operations, separately by runway. Summary statistics at the end of a run provide for each runway -- separately for landings, takeoffs and total operations -- the total throughput for the run, average hourly throughput, average total hourly delay, and the delay profile. Illustrative preprocessor and simulation outputs are shown in Figures A.1 and A.2.

In addition to throughput and delay information, DELCAP prints the final random number seed for use in subsequent runs. (See below for a more complete description of the random number generation process.)

Average hourly statistics (throughput or delay) are computed for each runway based on the time period within that hour during which the runway operating policy handles the operation in question. It should be noted that when periods of low traffic levels are averaged with busy periods, average throughput levels may appear much lower than customary throughput levels. In this case, hourly throughputs may be more appropriate and the user may wish to compute (off-line) separate average throughput levels for different time periods. The delay profile appears at the end of simulation output whenever delay output is called for. The profile shows the number of aircraft in each delay interval for each hour of the day. Delay is recorded for each landing at touchdown and for each takeoff at start of roll, so that the delay recorded to aircraft in a particular hour may include delays occurring in a previous hour. The figures thus describe

FIGURE A.1

Sample Preprocessor Output

```
THIS SIMULATION RUNS FROM  2.00 TO 22.00



                    AIRCRAFT DESCRIPTION

TYPE                 SPEEDS (KNOTS)       RUNWAY OCCUPANCY (SECONDS)
                   LANDING    LIFTOFF      LANDING       TAKEOFF


  1                  124.       120.          55.           33.

  2                  119.        90.          40.           27.

  3                  120.       120.          50.           32.

   TRAFFIC DESCRIPTION

TYPE      LANDING    TAKEOFF
            MIX        MIX


  1          5.         5.

  2         17.        17.

  3         78.        78.


AIRPORT CONFIGURATION



NUMBER OF RUNWAYS = 2

RUNWAY 1 (15  ) - OPERATED WITH RUNWAYS 2
OPERATION SEQUENCE
DEPART ON 1 ARRIVE ON 2

RUNWAY 2 (18  ) - OPERATED WITH RUNWAYS 1
OPERATION SEQUENCE
DEPART ON 1 ARRIVE ON 2



RUNWAYS 15   AND 18   INTERSECT AT A POINT  2000. FEET FROM THE
END OF RUNWAY 15   AND  2000. FEET FROM THE END OF RUNWAY 18   .


RUNWAYS 15   AND 18   ARE SEMI-DEPENDENT -
SIMULTANEOUS ARRIVALS ARE PROHIBITED
```

FIGURE A.1

Sample Preprocessor Output (Cont'd)

FRACTION OF LANDINGS OF EACH TYPE ON EACH RUNWAY

TYPE \ RUNWAY	1 (15)	2 (18)
1	.0000	1.0000
2	.0000	1.0000
3	.0000	1.0000

FRACTION OF TAKEOFFS OF EACH TYPE ON EACH RUNWAY

TYPE \ RUNWAY	1 (15)	2 (18)
1	1.0000	.0000
2	1.0000	.0000
3	1.0000	.0000

FIGURE A.2

Sample Simulation Output

		HOURLY THROUGHPUT			HOURLY DELAY PER AIRCRAFT		
HOUR	RUNWAY	LANDINGS	TAKEOFFS	TOTAL	LANDINGS	TAKEOFFS	ALL
3	1	0	36	36	0.	3.9	3.9
	2	37	0	37	3.4	0.	3.4
4	1	0	30	30	0.	8.4	8.4
	2	30	0	30	2.4	0.	2.4
5	1	0	38	38	0.	5.4	5.4
	2	37	0	37	4.9	0.	4.9
6	1	0	30	30	0.	14.6	14.6
	2	30	0	30	2.5	0.	2.5
7	1	0	28	28	0.	29.5	29.5
	2	29	0	29	3.7	0.	3.7
8	1	0	37	37	0.	44.6	44.6
	2	36	0	36	4.9	0.	4.9
9	1	0	35	35	0.	41.2	41.2
	2	35	0	35	7.0	0.	7.0
10	1	0	37	37	0.	33.1	33.1
	2	37	0	37	6.1	0.	6.1
11	1	0	29	29	0.	27.2	27.2
	2	26	0	26	3.9	0.	3.9
12	1	0	31	31	0.	41.8	41.8
	2	31	0	31	4.0	0.	4.0
13	1	0	37	37	0.	47.3	47.3
	2	37	0	37	13.2	0.	13.2
14	1	0	37	37	0.	44.5	44.5
	2	37	0	37	20.9	0.	20.9
15	1	0	36	36	0.	39.6	39.6
	2	37	0	37	26.3	0.	26.3
16	1	0	38	38	0.	36.0	36.0
	2	37	0	37	19.5	0.	19.5
17	1	0	39	39	0.	34.5	34.5
	2	39	0	39	19.9	0.	19.9
18	1	0	31	31	0.	24.2	24.2
	2	31	0	31	13.4	0.	13.4
19	1	0	34	34	0.	36.1	36.1
	2	34	0	34	7.9	0.	7.9
20	1	0	36	36	0.	20.6	20.6
	2	36	0	36	12.1	0.	12.1
21	1	0	38	38	0.	8.2	8.2
	2	38	0	38	15.1	0.	15.1
22	1	0	33	33	0.	2.7	2.7
	2	36	0	36	17.6	0.	17.6

FINAL RANDOM NUMBER SEED 360575540052

FIGURE A.2

Sample Simulation Output (Cont'd)

SUMMARY REPORT FOR THIS RUN

TOTAL THROUGHPUT

RUNWAY	OPERATIONS PERFORMED		
	LANDINGS	TAKEOFFS	TOTAL
1	0	690	690
2	690	0	690
TOTAL	690	690	1380

AVERAGE HOURLY THROUGHPUT

RUNWAY	OPERATIONS PERFORMED		
	LANDINGS	TAKEOFFS	TOTAL
1	0.	34.5	34.5
2	34.5	0.	34.5
TOTAL	34.5	34.5	69.

AVERAGE HOURLY DELAY

RUNWAY	DELAY (MINUTES)		
	LANDINGS	TAKEOFFS	TOTAL
1	0.	946.4	946.4
2	374.4	0.	374.4
TOTAL	374.4	946.4	1320.8

FIGURE A.2

Sample Simulation Output (Cont't)

DELAY PROFILE - NUMBER OF AIRCRAFT IN EACH DELAY CATEGORY BY HOUR

HOUR	NO DELAY	MINUTES DELAYED 00-05	05-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50	50-55	55-60	OVER 60
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	52	21	0	0	0	0	0	0	0	0	0	0	0	0
4	33	15	12	0	0	0	0	0	0	0	0	0	0	0
5	45	29	1	0	0	0	0	0	0	0	0	0	0	0
6	25	10	11	8	6	0	0	0	0	0	0	0	0	0
7	20	9	0	3	8	3	3	8	3	0	0	0	0	0
8	18	18	0	0	0	0	0	3	13	21	0	0	0	0
9	15	6	14	0	0	0	3	12	9	11	0	0	0	0
10	16	18	3	0	2	7	13	15	0	0	0	0	0	0
11	14	11	1	0	4	21	4	0	0	0	0	0	0	0
12	20	11	0	0	0	0	1	10	13	7	0	0	0	0
13	0	6	18	13	0	0	0	0	8	21	8	0	0	0
14	0	0	1	16	15	5	0	4	12	20	1	0	0	0
15	0	0	0	0	11	25	22	1	1	1	10	2	0	0
16	0	0	1	19	16	1	14	24	0	0	0	0	0	0
17	0	0	0	20	19	2	22	15	0	0	0	0	0	0
18	13	1	0	9	21	15	3	0	0	0	0	0	0	0
19	7	16	10	1	0	0	14	18	2	0	0	0	0	0
20	9	10	18	13	3	10	9	0	0	0	0	0	0	0
21	3	26	28	19	0	0	0	0	0	0	0	0	0	0
22	29	7	6	13	14	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	319	214	124	134	119	89	108	110	61	81	19	2	0	0

the delay experienced by operations occurring (touching down or starting roll) in the stated hour, not the delay actually experienced that hour or the delay experienced by aircraft scheduled to land or take off that hour.

A.2 Changes in Separation Criteria

With the advent of heavy aircraft (greater than 300,000 lbs. gross weight), wake turbulence problems have led to the imposition of separation rules requiring 5 mile separation for all non-heavy aircraft landing following a heavy, and 4 mile separation for a heavy following a heavy. All other aircraft combinations must be separated by 3 miles. Any non-heavy taking off behind a heavy must wait for two minutes after the heavy lifts off. Other takeoff separations are approximated in DELCAP by requiring that the second aircraft wait 20 seconds after the first lifts off. This eliminates all references to whether aircraft diverge or not and all necessity for treating departure paths. Other landing and takeoff separations may be input if it is so desired, but the revised DELCAP allows separation to depend only on the types of aircraft involved.

A.3 Improved Random Number Generator

Early test runs of DELCAP indicated that the random number generator available in the SIMSCRIPT system did not produce a sequence of numbers which were statistically "random" to a satisfactory degree. This has been remedied with the inclusion of a random number generator obtained from the NBS Statistical Engineering Laboratory. This generator requires a starting value (referred to as the "seed"), which is modified each time a random number is calculated. The final seed is printed out by DELCAP and can be used to start other runs. The sequence of random numbers produced depends entirely on the seed, so that runs can be replicated by using the same seed and on the other hand different traffic samples can be obtained by using different seeds. The seed is input and output as a 12 digit octal number.

A.4 Modifications in Operating Policy

The initial version of DELCAP allowed 4 different operating policies: landings only, takeoffs only, mixed operations where landings take precedence, and mixed operations in which landings and takeoffs alternate. To allow a more flexible sequencing procedure DELCAP was modified to let the user input the desired operation sequence. The user may provide any sequence of operations (of length up to 20), and this sequence will be repeated for the duration of the run.

In the earlier versions of the DELCAP model, operating policies were strategies for operating a single runway only. In the course of the "throughput validation" effort, it became evident [2] that allowing independent sequencing and generation of aircraft on close parallels or intersecting runways unduly favored takeoffs over landings, since the average minimum time between takeoffs is less than that between landings. This led to unrealistically high takeoff throughputs and also to a degradation of the landing throughput, because of the interference by takeoffs with the landings. In discussing these problems with knowledgeable authorities at the FAA, it became clear that in most control situations a pair of close parallels or intersecting runways would be operated cooperatively, with a sequence of operations applying to the pair. The most common example involves either parallels or intersecting runways, operated with one of the pair reserved exclusively for landings and the second for takeoffs. During periods when the number of desired arrivals and departures are approximately equal and traffic is heavy, landings will be spaced far enough apart to allow a takeoff to occur in between successive landings. In practice this means landings are spaced only slightly further apart than the minimum. Takeoffs will be alternated with landings by clearing an aircraft for takeoff as soon as the previous landing has passed the intersection (when the runways intersect) or as soon as the landing touches down (for close parallels). To accommodate a higher volume of takeoffs than landings, landings are spaced far enough apart that two (or more) takeoffs could occur between successive landings.

The DELCAP model has been modified to accommodate such policies. (See Appendix B for a description of the new version of event NXTOP, in which the bulk of the modifications occur.) In earlier DELCAP versions, a policy was specified for each runway by indicating the operation sequence for that runway. The modified version now requires that the user specify the number of the policy applicable to that runway. Then he must specify separately the policy itself in the form of two sequences, the first giving the operation sequence and the second giving the associated runway sequence. Therefore the i-th entry in the first sequence is the i-th operation and the i-th entry in the second sequence is the runway on which that operation is to occur. The number of operating policies provided may not equal the number of runways; it may be less if one policy applies to several runways; it may be more if policies are changed during the course of a run.

An example of the four policies used in the LaGuardia run reported in Section 3 is given in Table A.1. Policies 1 and 4 use only one runway, on which operations are alternated. Policies 2 and 3 both use two single-operation runways, with an operation on one alternating with an operation on the second. For instance for policy 3, takeoffs (operation 1) on runway 4 alternate with landings (operations) on runway 3.

TABLE A.1

Sample Operating Policies

POLICY NUMBER	SEQUENCE OF OPERATIONS AND RUNWAYS	
1	1	2
	3	3
2	1	2
	2	3
3	1	2
	4	3
4	1	2
	1	1

With the inclusion of this additional flexibility of operating policy, the user is now required to specify completely the set of policies. for any run, including the trivial sequence of operations having a single 1 for takeoffs only or a single 2 for landings only, together with the runway sequence whether or not only one runway is involved. This additional input requirement is a comparatively small price to pay for the extra flexibility and realism conferred by the more general operating policy approach. The preprocessor checks that the policy, specified in its input as applying to a given runway, can properly apply to it. It will not check, however, that another policy also affects this runway, since this may happen when policies change. Neither will it check that policy changes (after the initial policies) correctly apply to the runway they are associated with. This latter check is not made because the preprocessor does not have among its inputs the policy changes associated with each runway, since such changes are treated by the simulation as exogenous events.* Care must therefore be exercised by the user to ensure consistency for his input policies and policy changes initiated during a run.

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*The alternative is to complicate the simulation itself by adding consistency checking to the simulation code.

A.5 Changing Operating Policy During a Computer Run

In earlier versions of the DELCAP simulation, operating policies specified at the start of the run for each runway remained in force throughout the entire run. This approach was unacceptable for the LaGuardia exercise described in Section 3, since the operating policy in force changed several times during the day, and it was desired to include the effects of such changes on aircraft delay.

The main difficulty in incorporating the ability to change operating policy during a run lay in deciding how best to represent such changes. They can be classified into 3 categories:

1. use a runway surface not now being used,
2. change the sequence of operations on a runway now being used,
3. change the direction of operation of a runway now being used.

Any combination of these can also occur as a policy change.

In the first two cases little additional delay results from the change, unless it must be made so suddenly that established queues must be moved. It is assumed by the model that changes are not of this sudden type. Operations will occur on a new runway as soon as the first operation designated for that runway can take place under proper separation rules. Policy shifts involving sequence changes (including those from pure operations -- of landings or takeoffs only -- to mixed operations, or the reverse) are allowed to occur as soon as the last of the operations waiting (in queues) at the time the change is called-for has occurred. This is done to avoid difficulties arising because a policy may affect more than one runway. In practice, since operations are generated some time before their occurrence (touchdown or roll) on the runway, this extra time period required before effecting a policy change results in very little delay.

Additional delay does occur, however, for case 3 above. Whenever the runway whose direction is changed previously handled takeoffs, and is to handle landings after the direction change (it may or may not handle landings before and/or takeoffs after), it will be necessary to clear the takeoff queue before effecting the policy change, and also to allow additional time for the last takeoff to clear the final approach path before the first landing under the new policy can even start its approach. Since any runway-direction change may require moving queues around and establishing new approach patterns, an arbitrary time delay is required before initiation of a policy change whenever a change of runway direction is involved, and the model thus requires a fixed (input) time period between the last operation under the old policy and the first under the new.

Each policy change necessitates also that the distribution of traffic by runway be changed to agree with the new operating policies. (The program does not check that the two agree, so the user must be careful in providing input.) Policy change is handled by the DELCAP model as an exogenous event CHGOP, which reads the new policy number for each runway and the new traffic distribution by runway. The user must also specify for each runway whether or not the new policy involves a direction change on that runway. All policies themselves are input at the beginning of the

run, rather than with each change, and the user is responsible for consistency here also. Policy change is accomplished in CHGOP, whenever the policy change can occur immediately. In cases which require a delay, either to clear operations waiting or previously scheduled for the runway, or to effect a change of direction, the policy change occurs in CDIR. Descriptions of these routines are given in Appendix B, and input formats for the data required for a policy change appear in Appendix D.

A.6 New Preprocessor Standard Values

The preprocessor program has been designed to provide standard input values for each of six input categories. The user may elect to provide his own input or to accept the standard values, and indicate this decision by an option (non-blank characters if the standard is to be used, blanks for user provided values) on the preprocessor parameter card, the second preprocessor input card (see Appendix D for its format). Whereas the original version of the preprocessor was designed to have an input tape with standard input for several major airports, this tape is no longer referred to in the program and standard input is now provided internally through the use of the DATA statement.

Standard input for data group 1, aircraft type data, is shown at the top of the Sample Preprocessor Output in Figure A.1. The three standard aircraft types are:

1. heavy aircraft
2. light (piston) aircraft
3. other aircraft: larger piston aircraft and most jets.

The standard input for data group 2, aircraft type mix, appears below the aircraft type characteristics in Figure A.1. Standard input for data group 3, the departure and arrival rates, is set at 200 takeoffs per hour and 100 landings per hour, values which would saturate IFR operations at any large airport. These values are thus appropriate for throughput runs but not delay runs. To obtain realistic delay estimates, the user must supply realistic traffic levels.

Standard separations, data group 4, are those now required by FAA rules: 3 miles behind a non-heavy, 4 miles for a heavy behind a heavy, and 5 miles for a non-heavy behind a heavy for landings; and for takeoffs 20 seconds more than the runway occupancy time behind a non-heavy, 2 minutes for a heavy behind a heavy, and 2 minutes plus the runway occupancy time for a non-heavy behind a heavy. (The takeoff time separations are approximations involving several constraining rules.) Standard input for data group 5, the runway and operating policy data, specifies a single runway operated with landings and takeoffs alternated. The distance to the outer marker is 5 miles and the times to fly from handoff to the outer marker are 10, 13, and 10 minutes for the three aircraft types respectively. The standard input data for data group 6, the distribution of runway usage, have all aircraft using the single runway.

The changes described above have enhanced model capability and allowed it to reflect more accurately the sitatuion being simulated, without changing the basic philosophy of the DELCAP model. DELCAP was designed to be limited in scope to the calculation of airport runway throughput and the delays caused by terminal airside traffic. The design concentrated particularly on enabling the user to describe those elements of the terminal area which have primary impact on capacity and delay, without requiring him to provide excessive detail in input data. To ensure that DELCAP remains an easily used, convenient planning tool, candidate changes have all been examined against these criteria and only those meeting them have been implemented.

APPENDIX B

DESCRIPTIONS AND FLOWCHARTS OF SIMULATION EVENTS

Figure B.1 gives a general "flowchart" of the DELCAP simulation model routines. The word "flowchart" is somewhat of a misnomer in the context of a SIMSCRIPT model. The diagram indicates which event routines occur as a result of which other routines, but it does not give the order in which they are actually executed, since this is chronological.

Events GEN and EXGEN create flights, which are the units that move through the various events in the model. EXGEN is an exogenous event which occurs at times designated for the arrival into the system of specific flights. GEN creates flights in a stochastic manner. Stochastically generated flights are assigned an aircraft type and a landing or takeoff runway by the two functions PTYPE and PRWAY. Flights are constantly entering the system while other events are happening. GEN schedules the next occurrence of itself according to a Poisson process, while the next specific flight (if any are left) for EXGEN is always available. The event NXTOP finds the next operation (landing or takeoff) which is to occur on a particular runway. It is scheduled in one of two cases: (1) if the queue is empty when the current flight is filed in it, or (2) when the current flight has either begun to fly the final approach path to land or has left its gate to take off. Condition (1) is detected in GEN or EXGEN, and condition (2) in LAND or TOFF. NXTOP then schedules the next LAND or TOFF at the time the runway and/or final-approach path is free, as determined by the function FREER. Since there is a time gap between NXTOP and TOFF or LAND during which landings or takeoffs on other runways may have created new tieups for "this" runway, LAND and TOFF again determine the first time the runway is free (from FREER). Then the flight may land or depart, which in the DELCAP model implies tying up the appropriate points for a period of time sufficient to maintain the required separations. LAND or TOFF then reschedules NXTOP, and the cycle continues. When a tieup is no longer in force, the routine FTIEUP destroys it.

Several routines do not appear in this list, since they do not affect each flight. The BEGIN event (see Figure B.2) starts the simulation, and schedules the event ENDS which prints the simulation output and stops execution. The routine CHOUR (see Figure B.3) updates the current hour for output of delay and throughput, and reschedules GEN for the Poisson parameter for the new hour. The routine PRINT records the delay and throughput information at touchdown for landings, and at start-of-roll for takeoffs.

The exogenous event CHGOP reads the characteristics of a new policy and initiates the changeover if that can occur immediately. Otherwise CHGOP or NXTOP initiates CDIR when the changeover should occur. CDIR also handles the change of direction of a runway. The following sections will include descriptions of the events in Figure B.1, as well as CHGOP and CDIR.

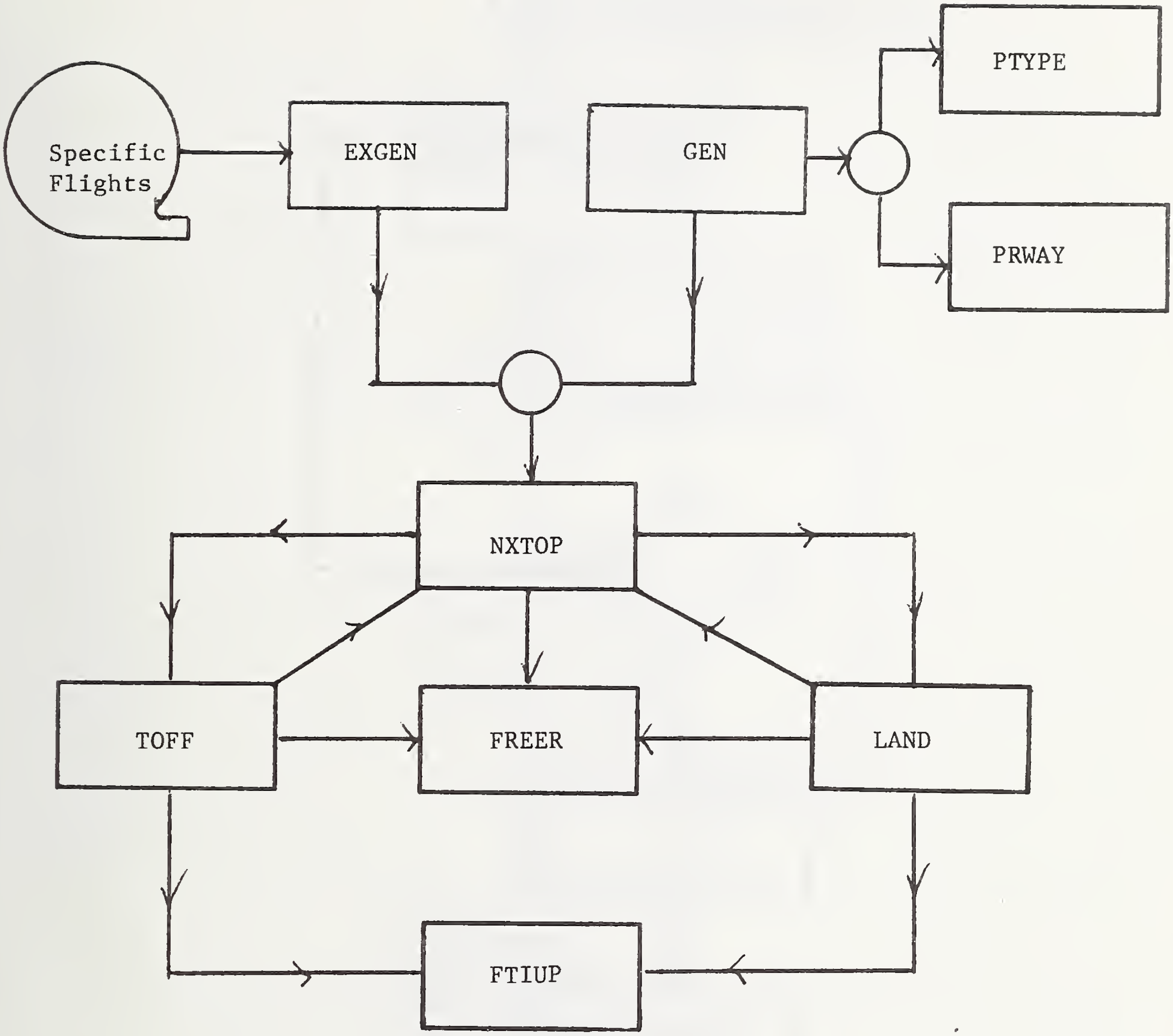

FIGURE B.1

Flowchart of the DELCAP Simulation Routines

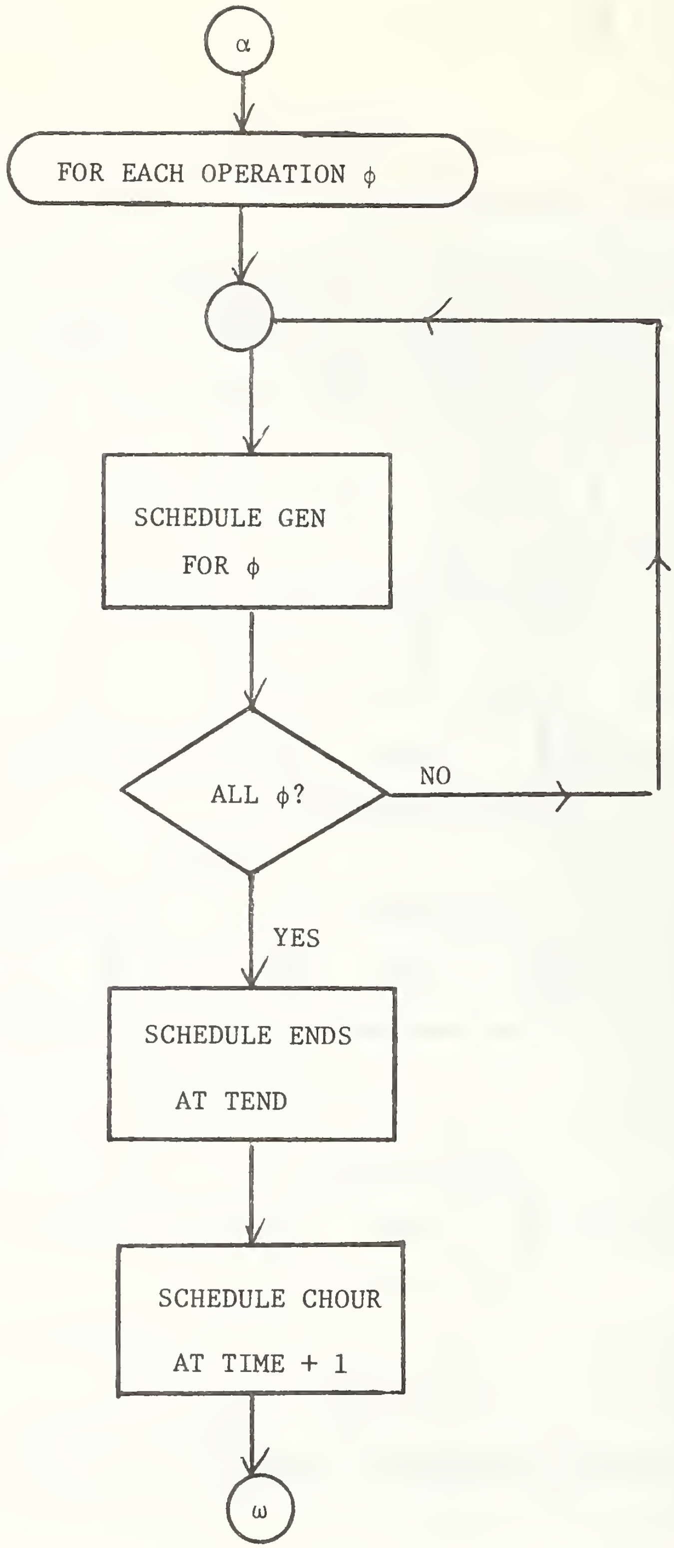

FIGURE B.2

Flowchart of Event BEGIN

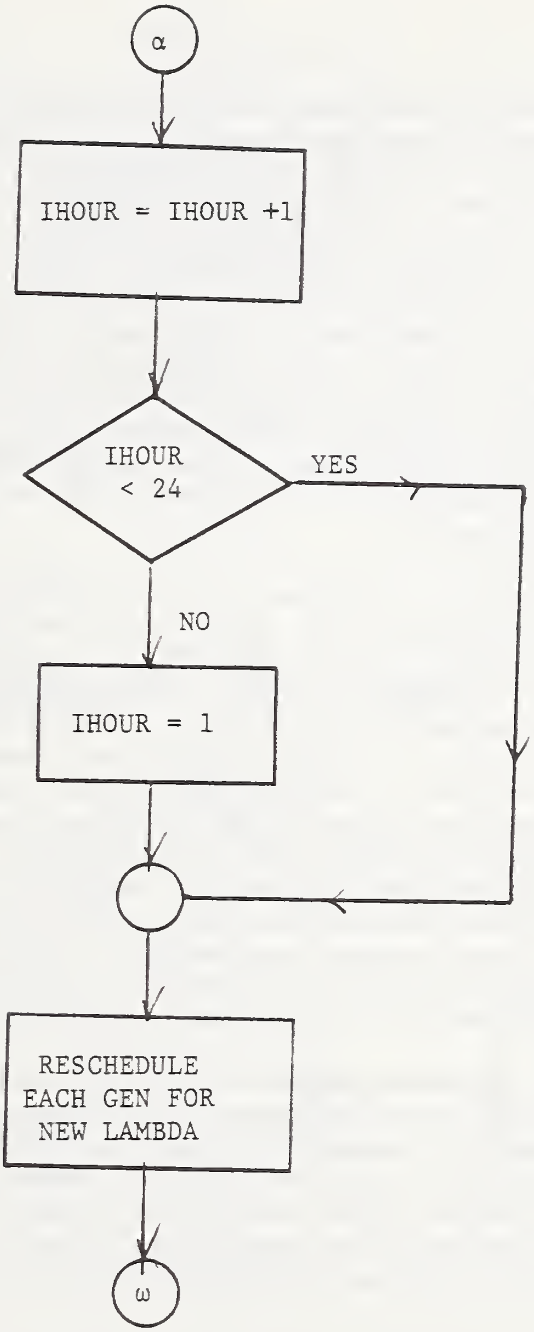

FIGURE B.3

Flowchart of Event CHOUR

B.1 Event EXGEN

This event creates exogenously-determined flights provided by the user. It, or the stochastic generation process or both, may be used for a particular run. When inputting the information for the routine EXGEN, the user must supply for each flight: the hour, minute, and second of entrance into the system, whether this flight is a takeoff or a landing, the runway used for takeoff or landing, and the aircraft type. The SIMSCRIPT system programs read these flights one at a time at the proper simulated time. Therefore, there is no limit on the total number of flights as long as the number simultaneously active (including both those generated by EXGEN and those produced by GEN) is sufficiently small to fit in core. (For a simulation run with 20 runways, 100 aircraft types, and 10 departure paths, there could be about 6,000 flights active at any given time. This, which is permitted in the present model, is far beyond the capacity of any existing airport to handle.)

Figure B.4 provides a flowchart for the EXGEN event routine. For a landing, the array TIN stores the time the current flight could (in the absence of other traffic) first cross the outer marker after flying from its handoff point. A takeoff's flight plan becomes active about 13 to 15 minutes before its scheduled departure. In the model this time period is divided into two segments, so that takeoffs are scheduled about the same time before start of roll as landings are before touchdown. The first of these time segments (about 10 minutes), which may be thought of as representing the time between when the flight plan becomes active and when the aircraft is cleared to leave its gate, is added to the current time and stored in TIN. (The second segment, about 5 minutes, may be thought of as representing a time interval between when the aircraft is ready to leave its gate and when it could start its roll down the runway; it will be described in greater detail in the section on the TOFF routine.)

After calculating the appropriate TIN, the EXGEN routine files the newly generated flight into the appropriate queue. There are two queues for each runway, one for landing aircraft, the other for takeoffs. The queues are organized in a first-in-first-out manner. This means there is no sequencing by aircraft type; when a slow aircraft precedes a faster one, the latter is not permitted to overtake the former, even if it could reach the outer marker first without thereby delaying the slower plane.

Each flight must remain in the queue until its TIN. Filing flights into the queue about 10 minutes before they could actually cross the outer marker or leave a gate provides a means for identifying the aircraft type of the flight that follows the current flight. This allows calculation of the proper tieup time to ensure that two aircraft remain separated by the required distance. This distance depends on the speeds of both aircraft involved, and so cannot be calculated until the type of the second plane has been determined.

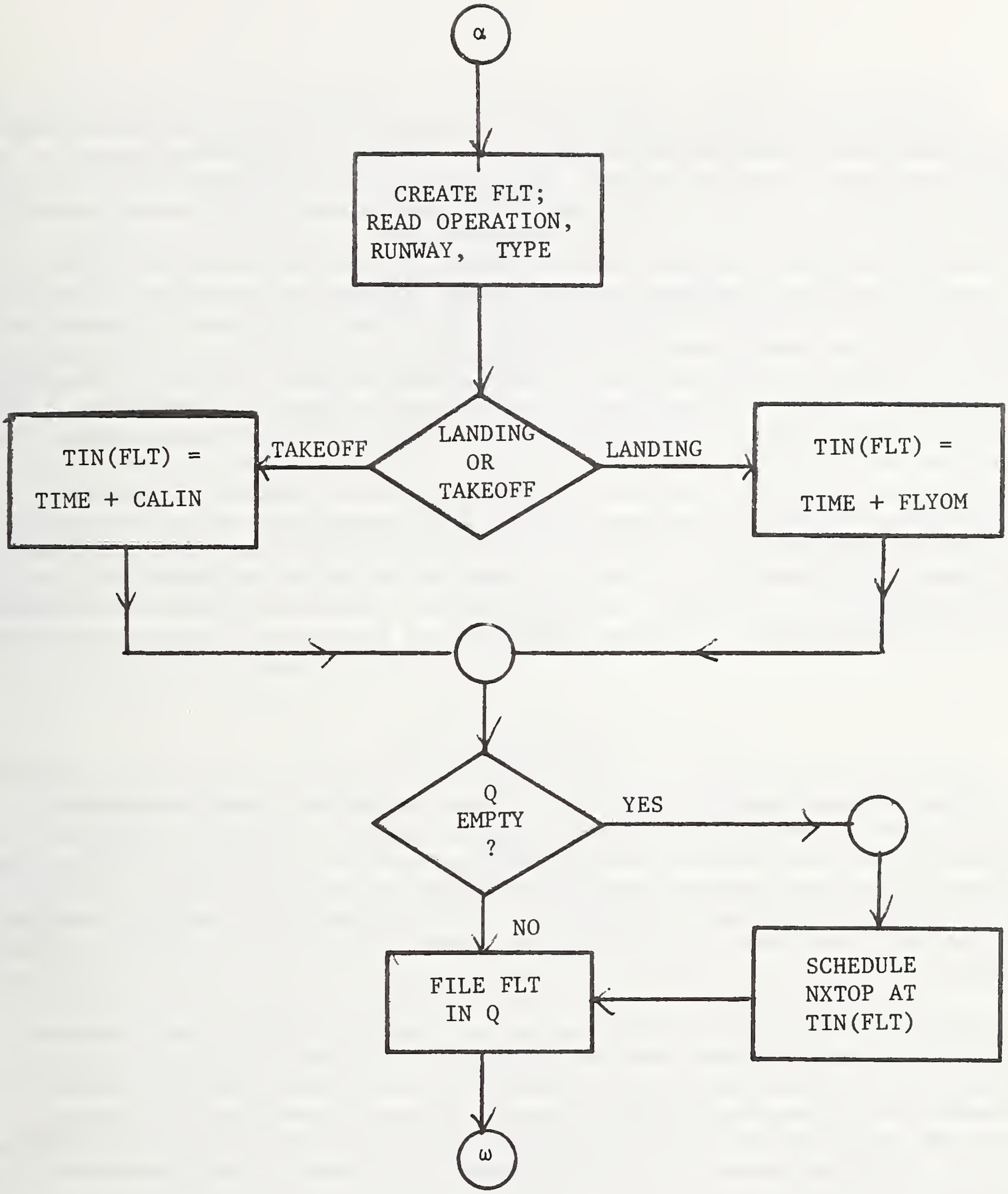

FIGURE B.4

Flowchart of Event EXGEN

If the queue was empty before the present flight was added to it, the NXTOP routine is scheduled to occur at TIN, which is the first instant when this flight could be removed from its queue. The NXTOP routine, which schedules the next operation (landing or takeoff) for a particular runway, thus occurs in one of two circumstances: either (1) a landing or takeoff has just occurred, or (2) the runway has been idle but there is now a new flight available for it. Case (1) will be described later in conjunction with the NXTOP, LAND and TOFF routines. In case (2), which is detected in the EXGEN routine, the appropriate queue will have been empty before the flight was filed in it. Therefore the NXTOP routine is scheduled for when the flight is first available to land or take off. However, an earlier NXTOP may have been scheduled in LAND or TOFF, since the other queue may not be empty. In this situation, NXTOP is scheduled, but when it occurs the next operation will already be defined (NEXT $\neq$ 0) and the NXTOP routine will be terminated. This means that NXTOP may be scheduled more often than necessary. The programming alternative was the coding of a much more complicated set of tests to ensure that NXTOP is scheduled only when necessary. This did not seem warranted, in view of the lack of computer-storage problems and the logical simplicity of the current test.

B.2 Event GEN

This event generates flights in a Poisson manner. Landings and takeoffs are generated separately, from two different sets of Poisson parameters. This routine is first scheduled by the BEGIN routine. BEGIN schedules two GEN's, one to create a landing flight and one to create a takeoff. From then on, the GEN routine schedules the next occurrence of itself. Therefore, within GEN we wish to sample from the Poisson distribution to reschedule GEN for the next entry ("arrival") of another aircraft into the simulated system.

The procedure used in the computer for sampling from a distribution is based on the fact that the range of <u>any</u> cumulative distribution is uniformly distributed over the interval [0,1]. In the case here, we have assumed Poisson generation, so the probability of an arrival in a time period of length dt is μdt (plus comparatively infinitesimal terms), where μ is the expected number of arrivals per unit of time. Then the probability $q(T)$ that the next arrival will occur in at most T units of time is

$$q(T) = \text{prob } (t \leq T) = 1 - e^{-\mu T}.$$

Since q is a cumulative distribution, its range is uniformly distributed over the interval [0,1]. We therefore employ a standard computer subroutine to choose a random number R from this uniform distribution, and then find the T for which $q(T) = R$, namely

$$T = -\lambda \ln (1-R)$$

where $\lambda = 1/\mu$. The next instance of GEN is scheduled to occur in T time units. (Note that our time unit for the simulation is the hour, so λ is

the reciprocal of the number of arrivals per hour.) Input to the simulation contains two sets of values for λ for each hour of the day, one for landings and one for takeoffs. As noted earlier, on the hour, each hour, the next GENs, one for a landing and one for a takeoff, are rescheduled according to the λ for the appropriate hour.

In the event EXGEN, the type and the runway are provided as part of the input. In the stochastic version GEN, however, these three items are obtained by sampling from the appropriate distributions. The simulation is provided (by the preprocessor) with the cumulative distributions of (1) type of aircraft, one for landings and one for departures, and (2) runway use by each type of aircraft for landings and also for departures. The two functions PTYPE and PRWAY perform the sampling processes.

Figure B.5 provides a flowchart of the GEN routine. After rescheduling the GEN routine for the next landing or next departure (depending on the current operation), and sampling to obtain a type and runway for the current flight, the remainder of the routine is the same as for the EXGEN routine. The appropriate value of TIN is calculated, the flight is filed in its proper queue, and if the queue was empty before this flight was filed in it then the NXTOP routine is scheduled at TIN.

B.3 Event NXTOP

This event finds the next operation, landing or takeoff, which will be scheduled to occur on a runway. Figure B.6 is a flowchart of this routine. Because of the new more sophisticated operating policies to be simulated, this routine has required significant changes from the original version of DELCAP. A search is made, starting with the next position (stored in LAST) in the policy sequence applying to this runway, for the first flight which can be scheduled immediately under this policy. If no flight can occur immediately, the search continues through the policy to determine the flight which will be available soonest, and LAND or TOFF is scheduled for that flight. In addition to determining the next operation to be scheduled under the policy, the NXTOP routine also recognizes when a change in policy, which is not initiated by CHGOP, must occur. If the next flight to be scheduled is the last flight in the queue at the time the policy change was requested in CHGOP (i.e. if the current flight FLT = QF(k,i)), then the QF's for the other runway, operation combinations for this policy are checked. If all QF's are zero, the policy changeover is scheduled to occur when the current flight either starts its approach or leaves its gate. This is accomplished by scheduling CDIR at the (same) time for which the LAND or TOFF routine was scheduled.

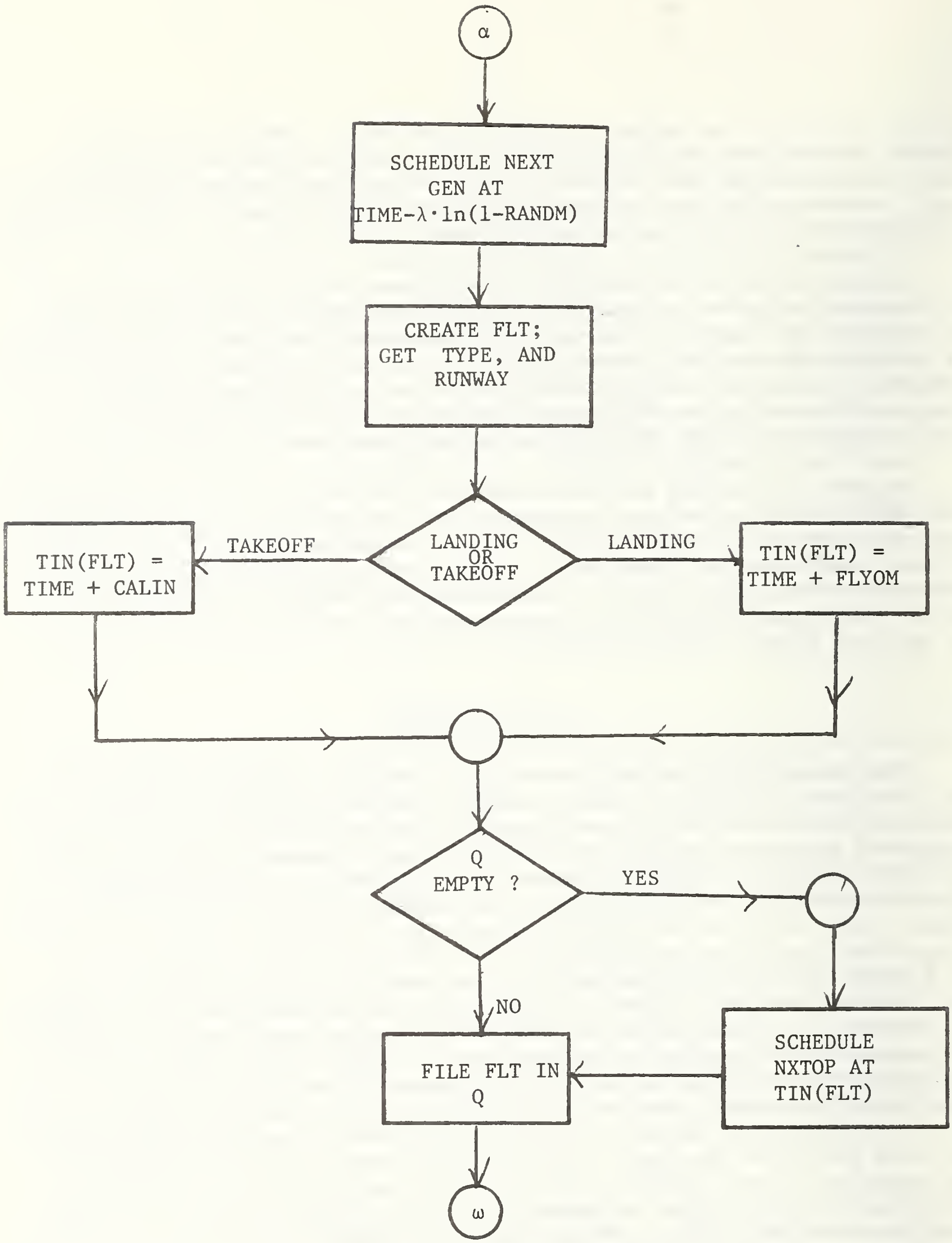

FIGURE B.5

Flowchart of Event GEN

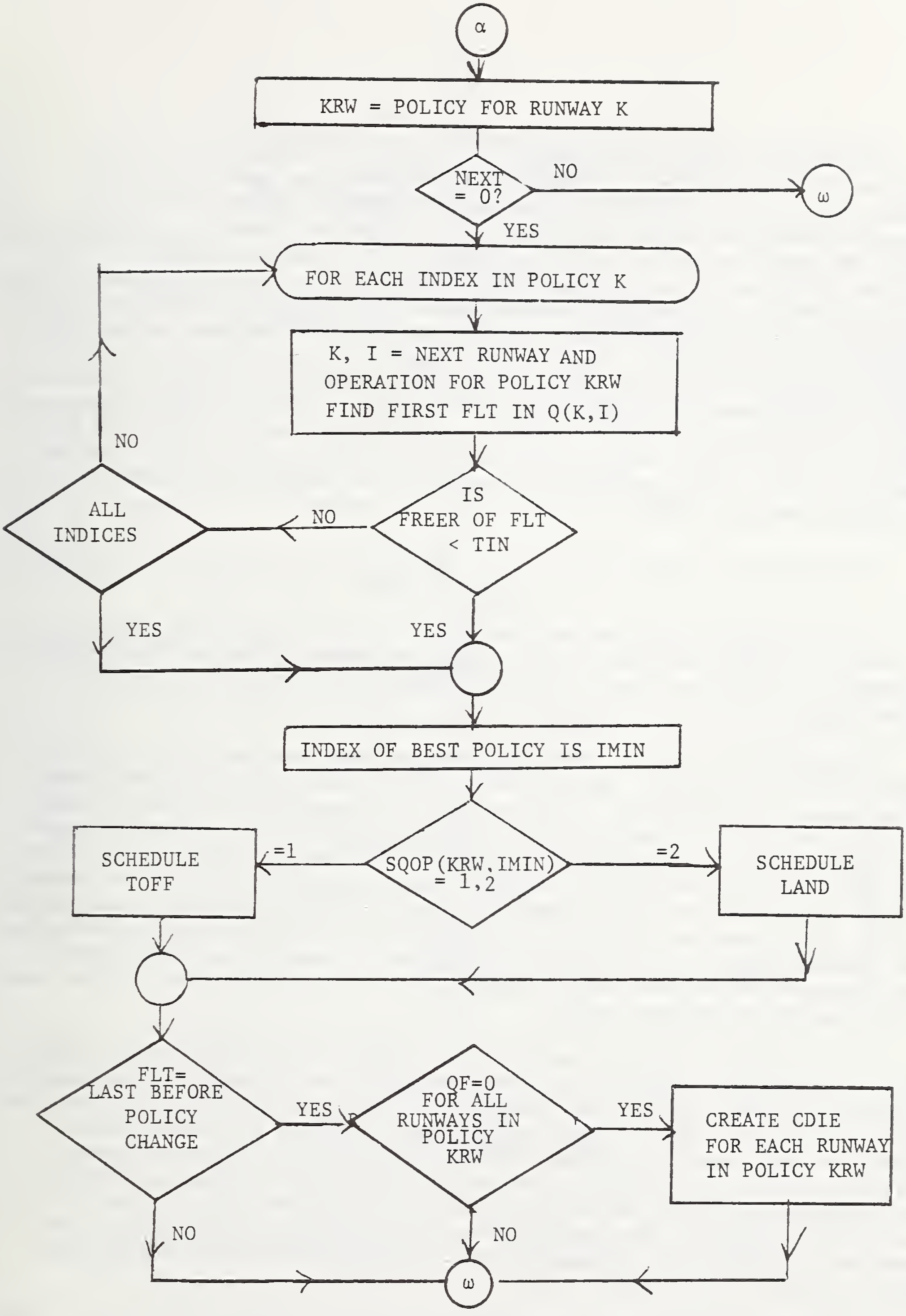

FIGURE B.6

Flowchart of Event NXTOP

The NXTOP routine is scheduled in one of two instances: (1) the LAND or TOFF routine has occurred, or (2) a queue was empty and a new flight has just been filed. In the second instance, NXTOP is scheduled for the time TIN at which the flight could first be scheduled. However, since the other queue for the runway need not be empty or a LAND or TOFF routine could just have occurred, another NXTOP may already be scheduled for this runway. To avoid error because of having several NXTOPs scheduled at once, an array NEXT with an entry for each runway has been introduced. Originally it is zeroed. When a next operation for a runway has been found by NXTOP, NEXT is set equal to 1 (for a takeoff) or 2 (for a landing). Then NEXT is zeroed in the LAND or TOFF routine. Therefore NEXT is non-zero precisely when a LAND or TOFF is scheduled but has not yet occurred. NXTOP proceeds to find a next operation for a runway only if NEXT for that runway is zero. This condition is tested at the beginning of NXTOP, and if NEXT is non-zero NXTOP is immediately terminated.

B.4 Function FREER

This function finds the earliest time a particular flight can land or take off without violating the separation rules. FREER is first called in NXTOP, to find the time at which the LAND or TOFF routine should be scheduled.

There may be a gap between the time the NXTOP routine occurs and the time LAND or TOFF occurs, during which other flights might add new tieups which require postponement of the operation in question. Therefore FREER is called again from LAND or TOFF, to determine when the landing or takeoff may actually occur. Figure B.7 contains a flowchart of the function FREER. The left-hand side refers to landings, the upper right-hand side to takeoffs and the lower portion of the chart to both. T is the maximum of TIN and the current time, used to single out for examination only those tieups affecting the current flight. The array TR is created to contain the time (TMAX) each tieup affecting the flight will no longer be in force, and J is a count of the number of entries in TR.

For landings, both the set of tieups (OMTI) associated with the outer marker and the set (THTI) associated with the runway threshold are examined. The time of tieups in THTI is translated to the outer marker by subtracting off the amount of time it takes the current flight to fly from the outer marker to the runway threshold; this reflects the fact that the runway threshold need only be free as the current flight gets there, not before. For takeoffs, only the set of tieups (ERTI) associated with the end of the runway are examined. The time of these is translated to the gate by subtracting off TDMIN, since takeoffs are scheduled before they leave their gates to taxi to the runway.

If there are no tieups affecting the current flight (i.e. J = 0), FREER is set equal to T. If only one tieup affects the current flight (i.e., J = 1), then TR (1) will contain the time at which that tieup will no longer impede the start of the landing or takeoff procedure, and so FREER is set equal to

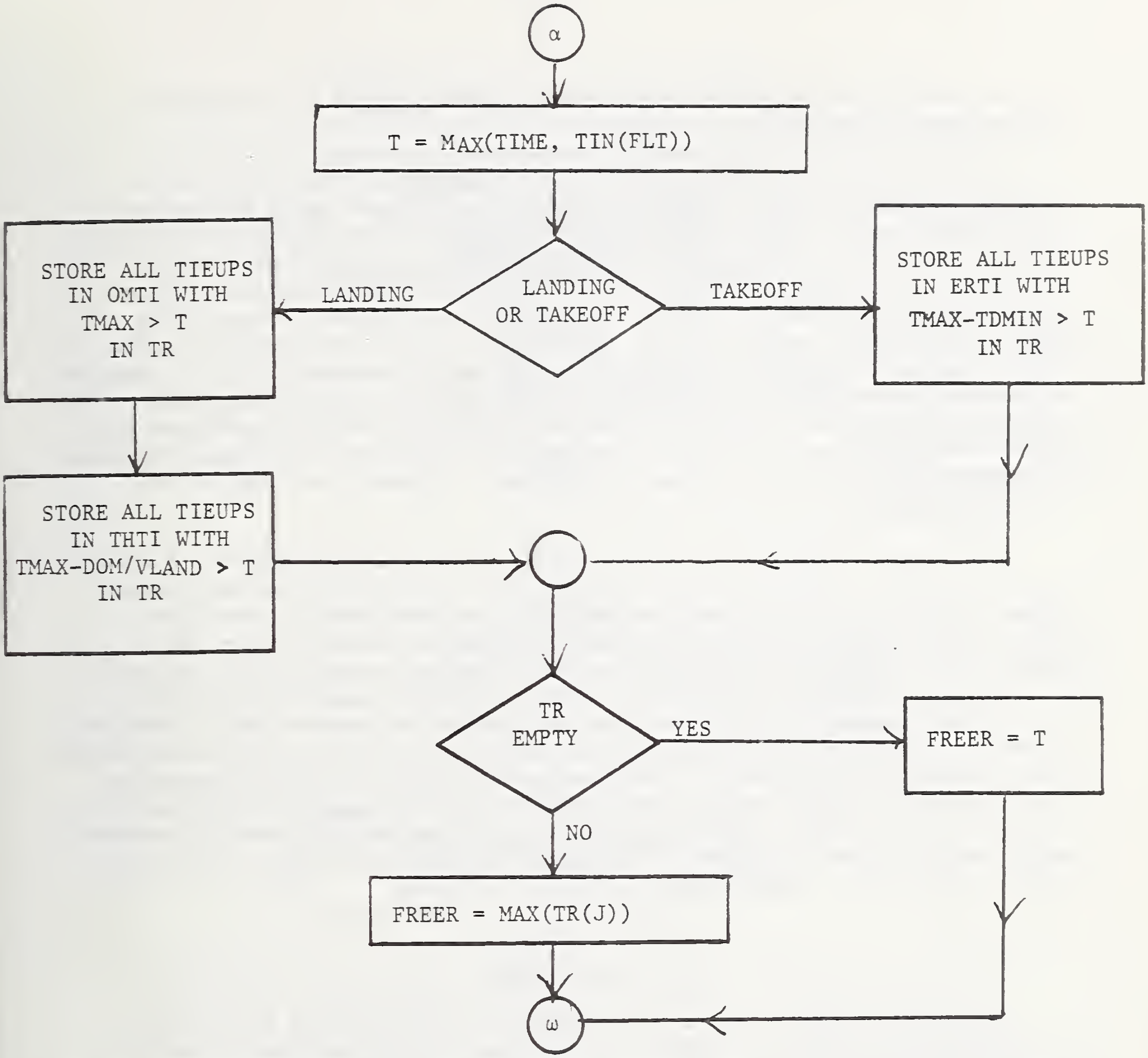

FIGURE B.7

Flowchart of Function FREER

it. If several tieups affect the current flight, FREER is set equal to the maximum of the TR's.

It should be clear from the previous description that this routine does not attempt to fit a flight in between two others, even if the gap between the two is wide enough. To do so would require a great deal more coding. The crux of the difficulty is how wide a gap is "wide enough". The tieups occurring as a result of the inserted flight must not affect any previously scheduled flight. This means that all the tieups which LAND or TOFF would create must be examined to see if they would interfere with a landing or takeoff already scheduled or in progress. This is similar to performing the whole of the LAND or TOFF routine, and involves the additional burden of identifying the flight which is being interfered with. (It is no longer just the first in a queue.) Therefore the simpler procedure, of waiting until the last tieup is no longer in force, was used in the DELCAP simulation.

One further difficulty can arise when a slow landing follows (i.e. lands later than) a fast takeoff. NXTOP is called as soon as the takeoff leaves its gate. The landing therefore is not permitted to cross the outer marker before then, since FREER is at least T which in turn is at least the current time of NXTOP. However, if the landing is slow enough it could in principle be scheduled earlier, and the takeoff would still be able to precede it while maintaining the required separation. Therefore, although the sequence of operations on the runway must be a takeoff followed by a landing, the sequence of routines should really be LAND followed by TOFF. This difficulty has not been resolved, but in sample debugging runs it occurred only about 2 to 3% of the time, and added only about 30 seconds extra delay at each occurrence. Therefore it does not seem to affect the DELCAP results by a significant amount.

B.5 Event LAND

The primary purpose of both the LAND and TOFF routines is to tie up the appropriate points in order to ensure that following flights remain properly separated from the current landing or takeoff. Figure B.8 is a flowchart of LAND. LAND removes the first flight from the landing queue for the appropriate runway. Then it calls FREER to find when the runway and final approach path are first free so that this flight may cross the outer marker.

The separation rules which apply to a landing, and their implementation, are discussed below:

(1) No two aircraft may occupy the same runway at the same time. This rule is implemented by tying up the runway threshold (for landings) or the end of the runway (for takeoffs) for the time the current landing will occupy the runway.

(2) Two landings must be separated by a minimum distance (called SEPLL, in DELCAP) and depending on the two aircraft types involved. We assume a constant nominal final-approach speed, depending on aircraft type. Therefore, the point at which two landings are closest while always main-

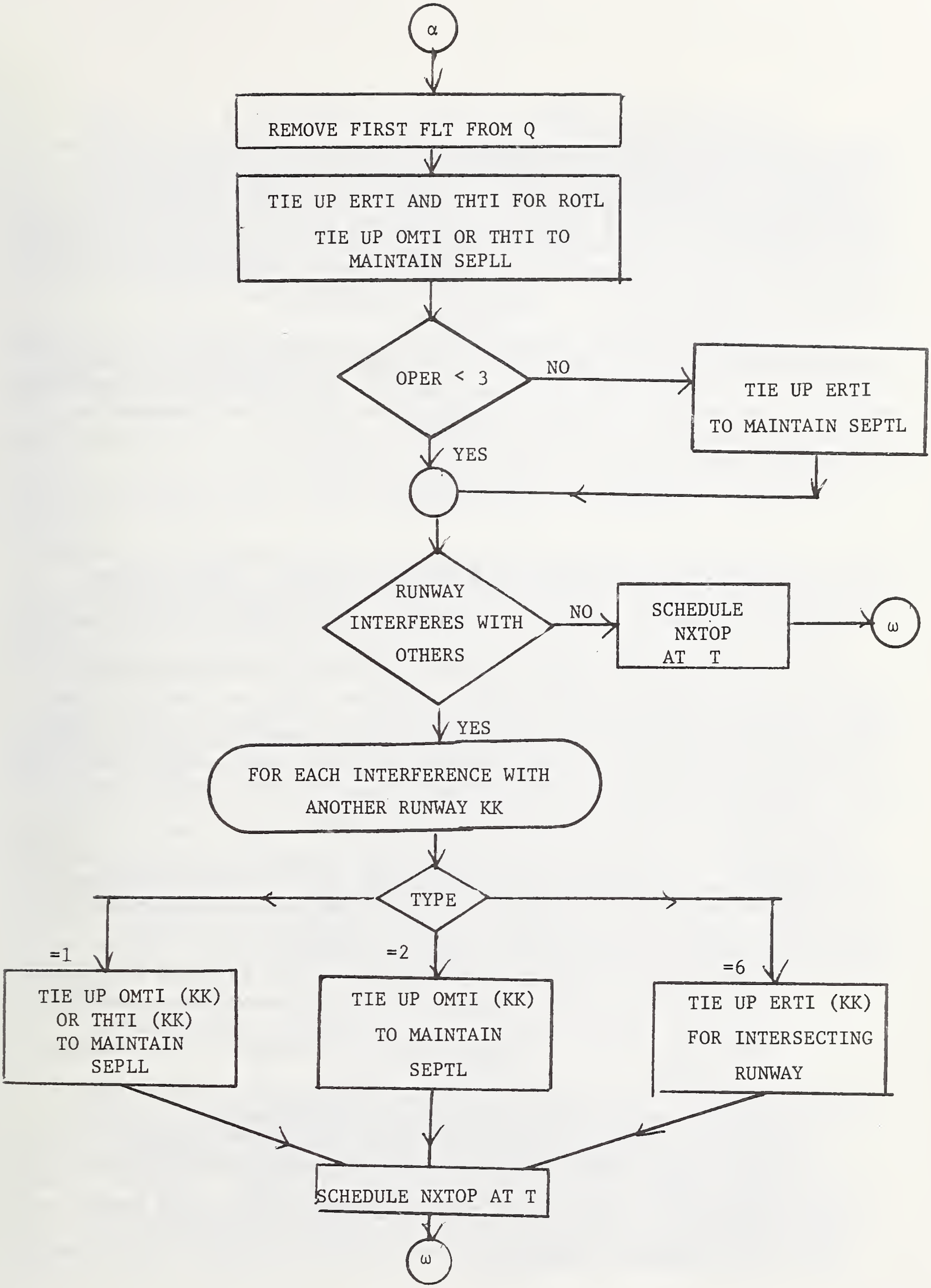

FIGURE B.8

Flowchart of the Event LAND

taining the required separation depends on the relative speeds of the two planes. If the first (of aircraft type i) is faster, they will be closest when the first crosses the outer marker. In this case the outer marker is tied up for the time it will take the second (of aircraft type j) to fly SEPLL (i,j). If the second is faster, the two planes will be closest when the first just touches down. In this case the runway threshold is tied up from touchdown of the first until that time plus the time for the second to fly SEPLL (i,j).

(3) A landing must be separated from a preceding takeoff by a required distance (called SEPTL in DELCAP). The standard present value for SEPTL is 2 miles. As noted above, the final-approach speed is treated as constant. Under the assumption of a single constant acceleration for a takeoff on the ground and in the vicinity of the airport, the distance the landing must be from the takeoff when the latter starts its roll is

$$\text{SEPTL} + 0.5\, v^2 \cdot \text{ROTT/S},$$

where v is the speed of the landing, S is the liftoff speed of the takeoff, and ROTT is the runway occupancy time for the takeoff. (This formula is derived in Appendix F of [4].) The end of the runway is therefore tied up from the time the landing passes this point until touchdown time.

Tying up a point is accomplished in the simulation by creating a temporary entity called a TIEUP, with attributes TMIN, the time the tieup goes into force, and TMAX, the time the tieup is no longer in force. The TIEUPs are filed in one of the sets OMTI, THTI, or ERTI, which are scanned in FREER to decide when the runway and final approach path airspace are free. Once the TIEUP is no longer in force, it is removed by the FTIUP routine which is scheduled in LAND as the TIEUP is created.

In addition to tying up points on the same runway, points on interfering runways must be tied up. Two arrays RPT and TPT control these interferences in the DELCAP simulation. For each runway and interference, RPT contains the runway being interfered with, and TPT contains the type of interference. There are six types of interference:

1 Landings on one runway must be separated from landings on the other runway by SEPLL, depending on the aircraft types involved.
2 Landings on the one runway must be separated from preceding takeoffs on the other runway in the same manner as that described in (3) above.
3 Takeoffs on the one runway must be separated from following landings on the other as described in (3) above.
4 Takeoffs on the one runway must be separated from takeoffs on the other runway by the same separation as takeoffs on the same runway.
5 Takeoffs on the two runways are separated by the times in the array SEP2.
6 The two runways intersect.

Types 1, 2, and 6 apply to landings. Tieups for interference types 1 and 2 are computed in a manner similar to (2) and (3) above. For intersecting runways, a takeoff or landing on another runway may not be on the runway between the time the current landing touches down and the time it passes the intersection or turns off, whichever occurs first. The time for an aircraft to travel from touchdown to an intersection a distance D from the end of the runway is

$$(1/A)(-v + \quad v^2 + 2AD)$$

where v is the landing speed and A is the acceleration of the landing. We assume A is constant, so

$$A = (v_1 - v)/ROTL < 0,$$

where v_1 is the turnoff speed of the landing, v is the final approach speed, and ROTL is the runway occupancy time. This formula is derived in Appendix G of [4].

The RPT and TPT lists are scanned, and appropriate tieups are initiated to maintain required separation between the current landing and operations on other runways. As each tieup is created, it is filed into the set for the point being tied up. At this same time, an FTIUP is scheduled to destroy the tieup once it is no longer in force.

Once all the necessary tieups have been created, the LAND routine sets NEXT = 0 and schedules NXTOP for the time the current landing crosses the outer marker. Then the delay to this flight is calculated as the difference between the time it crosses the outer marker, and TIN (which is the first time it could cross the outer marker were there no other aircraft present). The PRINT routine is scheduled at the touchdown time for this landing. PRINT adds the delay to this flight to the total delay, and increments the number of landings for the correct hour. Since all tieups to maintain separation from this landing have been created and since the delay for this flight has been calculated, the flight is no longer needed, so it is destroyed. This completes our description of the landing routine. The takeoff routine performs similar tasks related to takeoffs.

B.6 Event TOFF

Figure B.9 is a flowchart of the TOFF routine. Much of it is similar to the LAND subroutine. The first flight is removed from the landing queue and FREER is called to ascertain the first time the flight can taxi to takeoff. Tieups are created to maintain separation, both on the same runway and on others where there is interference. NXTOP is scheduled for the time specified by FREER, the delay is calculated, and the flight is destroyed. Thus the overall structure of TOFF is similar to that of LAND.

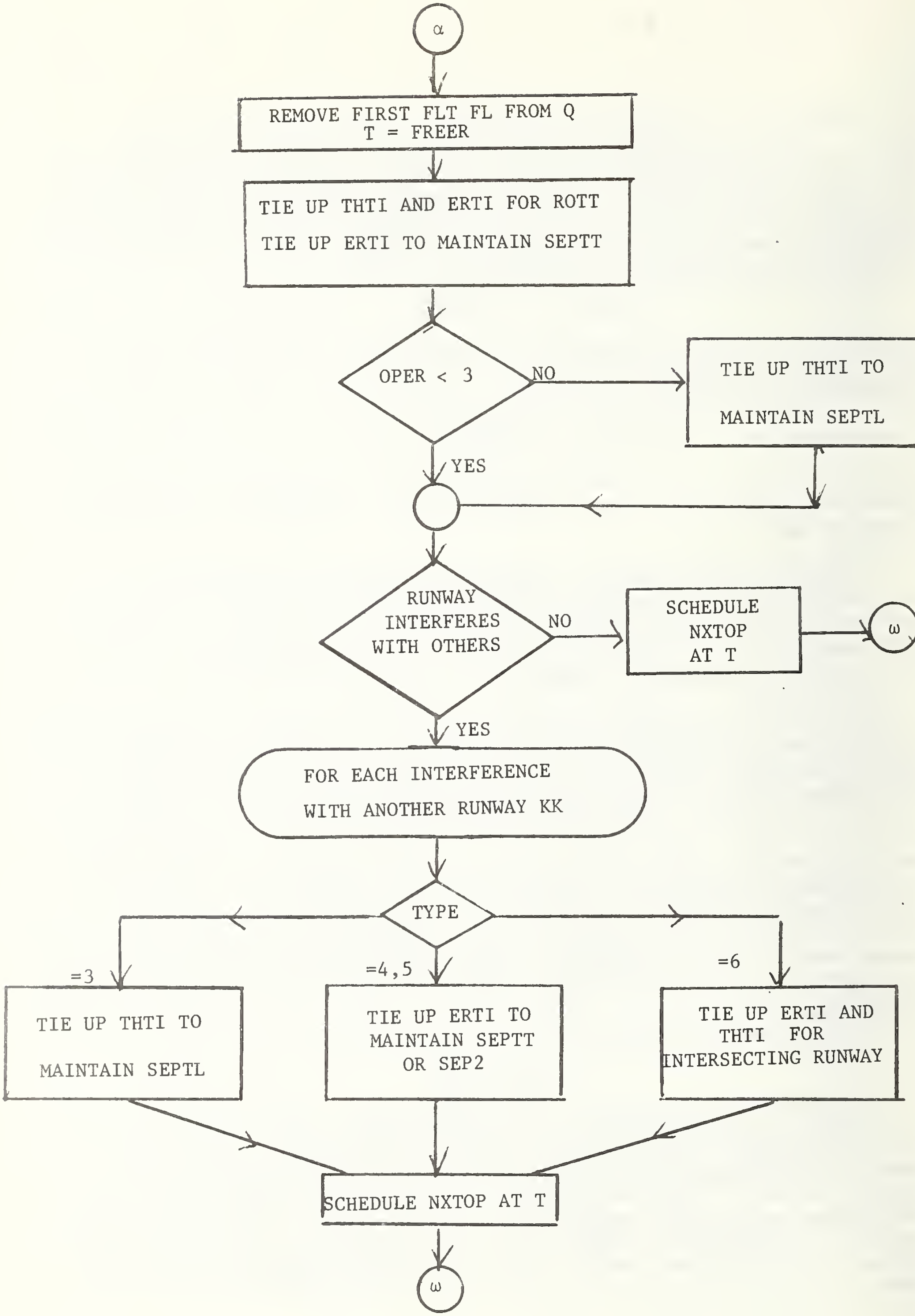

FIGURE B.9

Flowchart of Event TOFF

Takeoffs, however, are special in one way. They enter the system several minutes before scheduled takeoff and the TOFF routine occurs later still before takeoff. The reason for this early scheduling of takeoffs can best be described here, in the context of the TOFF routine. Takeoffs are scheduled early so that their scheduling can be compatible with that of landings. Landings need to be scheduled before touchdown, since they must be properly separated from other operations along the whole of the final approach path. If takeoffs were scheduled only at start-of-roll, a following landing could be scheduled no earlier than that start-of-roll. In other words, the following landing could not cross the outer marker until the preceding takeoff had started its roll. It would greatly complicate the model if landings and takeoffs for one runway were scheduled in an order different from that in which they occur in LAND and TOFF. By scheduling takeoffs early, landings and takeoffs can be treated in the same manner. As noted above, there is still a residual difficulty when a very slow landing follows a fast takeoff, but for the most part, scheduling takeoffs early permits proper sequencing and scheduling on a dual-use runway.

One may still ask, "Why generate takeoffs so early?" It is necessary to generate takeoffs at least 3 to 5 minutes (depending on the separation rules) before they are scheduled by TOFF. When calculating the tieup duration needed to maintain separation from following aircraft, it is necessary to know the type of the following aircraft. Therefore takeoffs have to be generated as far ahead (in time) of scheduling in TOFF as the greatest time separation required between aircraft.

The careful reader may wish to inquire whether this procedure is indeed not too artificial. We note in response that these time intervals can be interpreted in terms of real events. The time between flight generation and scheduling of TOFF may be thought of as the minimum time ahead of departure at which a flight plan can be filed. Such a minimum time is in fact required at the more congested airports, and as more terminals become congested this practice will become more widespread. Also, with the addition of computer processing of flight plans, a minimum filing time is quite likely. The time between scheduling and start-of-roll may be thought of as the time for the aircraft to leave its gate, taxi to the runway, and complete final checkout. In the model, queuing for takeoff would then occur before leaving the gate, although at most terminals gate space is limited and there are parking ramps for waiting. This is another instance of a situation in which we are interested in the <u>length</u> of a time interval but not in <u>where</u> the aircraft is during that interval. We would be interested in where the aircraft actually is only if this were to affect whether the aircraft could turn onto the runway when the runway is free. The DELCAP model does not include any ground operations, and therefore, the delay figures do not include delays incurred during ground operations. Future model modifications might address this additional source of delay.

To return to our discussion of the TOFF routine, we will now describe the separation rules applying to a takeoff, and their implementation.

(1) No two aircraft may simultaneously occupy the same runway. This rule is implemented in the same manner as it was in LAND. The runway threshold and the end of the runway are tied up from start-of-roll to liftoff.

(2) Separation between departing aircraft depends on the types of aircraft involved, since under current rules extra time is required for aircraft departing behind a heavy, and this time is less if the following aircraft is also a heavy than if it is not. Separation times are stored in the array SEPTT, which is a two-dimensional array depending on the aircraft types involved.

(3) A takeoff must be separated from a succeeding landing. The process here in TOFF is similar to that described for separation (3) of LAND. The runway threshold is tied up from start of roll until that time plus

$$(1/S)(\mathrm{SEPTL} + 0.5\ v^2\ \mathrm{ROTT}/S)$$

where v is the landing speed, S is the liftoff speed of the takeoff, and ROTT is the runway occupancy time of the takeoff.

Each tieup created is filed in the appropriate set ERTI, for the end of the runway, or THTI for the runway threshold. Along with each tieup, the routine FTIUP is scheduled for when the tieup is no longer in force.

TOFF also ties up points on interfering runways in order to ensure that the required separation from the current takeoff is maintained. Of the six types of interference listed in the description of the LAND routine, four pertain to takeoffs:

3. Takeoffs on one runway must be separated from following landings on the other runway.
4. Takeoffs on one runway must be separated from takeoffs on the other runway by the same time as takeoffs on the same runway.
5. Takeoffs on the two runways must be separated by the times in the array SEP2.
6. The two runways intersect.

Tieups for types 3 and 4 for different runways are computed in the same manner as separations (3) and (2) above for one runway. Tieups for type 5 are computed in a manner similar to that of separation (2) above, except that a second array SEP2 is used instead of SEPTT. SEP2 contains time separations required between aircraft on different runways. Type 6 is handled for takeoffs in the same manner as for landings. The threshold and end of the second runway are tied up from the time the takeoff starts its roll until it has passed the intersection.

The remainder of the takeoff routine is the same as the landing routine. NXTOP and PRINT are scheduled, delay is calculated, and the flight is destroyed.

B.7 Event FTIUP

This event destroys a tieup as soon as it is no longer in force. A flow chart appears as Figure B.10. These "erasures" free computer storage for new flights and tieups, and make searching the sets in FREER easier. Since the sets OMTI, THTI, and ERTI are ordered by TMAX (the time the tieup is no longer in force), FTIUP only needs to remove and destroy the first tieup in the appropriate set.

B.8 Event CHGOP

This event, whose flowchart appears as Figure B.11, reads the new policy to be used for each runway together with the new runway usage, distributions, and initiates policy changeovers whenever the changeover can occur immediately. The array QF(k,i) indicates for each runway and operation the status of the runway for changing policy. CHGOP sets up QF so that QF = 0 if either the queue for that runway and operation is empty or if the runway was not used under the previous set of policies. If, on the other hand, the runway was previously used and has aircraft in its queue, QF for that runway and operation is set equal to the last flight in that queue.

The old policy for a runway is stored in the array INDX and the new policy in TNDX. Changing the policy consists of replacing INDX with TNDX and setting TNDX to be zero. The change can occur only when all the QF's for all runway/operation combinations in the policy are zero. However, if the policy change involves a change in direction of a runway, it cannot be initiated immediately, and in this case the routine CDIR which handles runway direction changes is scheduled at the current time. If any QF's are non-zero then the policy change is initiated by NXTOP, which detects when the next aircraft scheduled is the flight stored in QF, and calls CDIR to initiate the policy change.

B.9 Event CDIR

Figure B.12 is a flowchart of event CDIR. This event also initiates policy changes, and can be scheduled either from CHGOP or NXTOP. It first tests if a runway-direction change is involved in the policy change. If that is so, the changeover must be deferred for a time (AFIN(k)). To accomplish this, CDIR is rescheduled after a lapse of AFIN, and CHGD is zeroed so that when CDIR is next entered the change will not be further deferred. When CHGD is zero, CDIR changes INDX to be TNDX and zeroes TNDX, thus actuating the changeover.

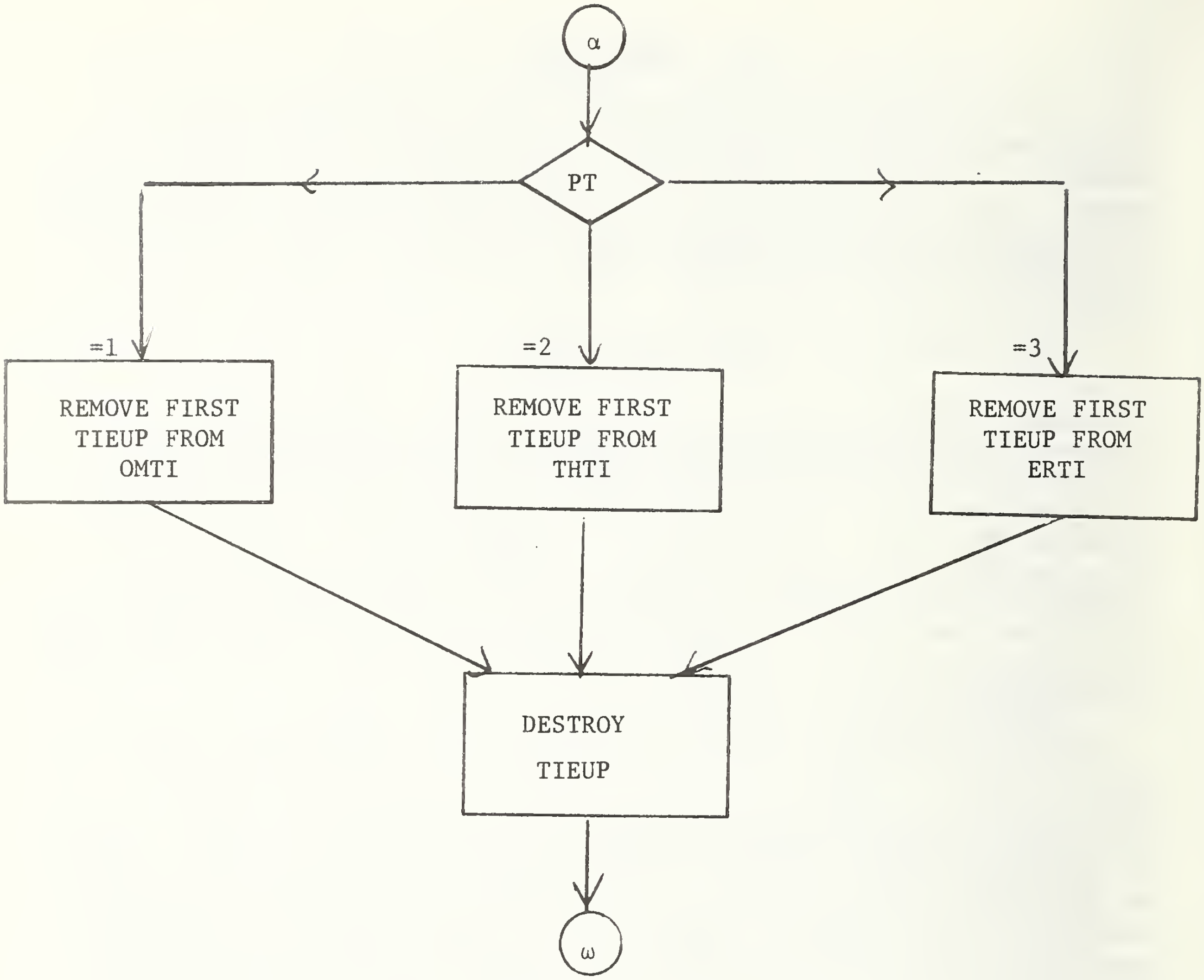

FIGURE B.10

Flowchart of Event FTIUP

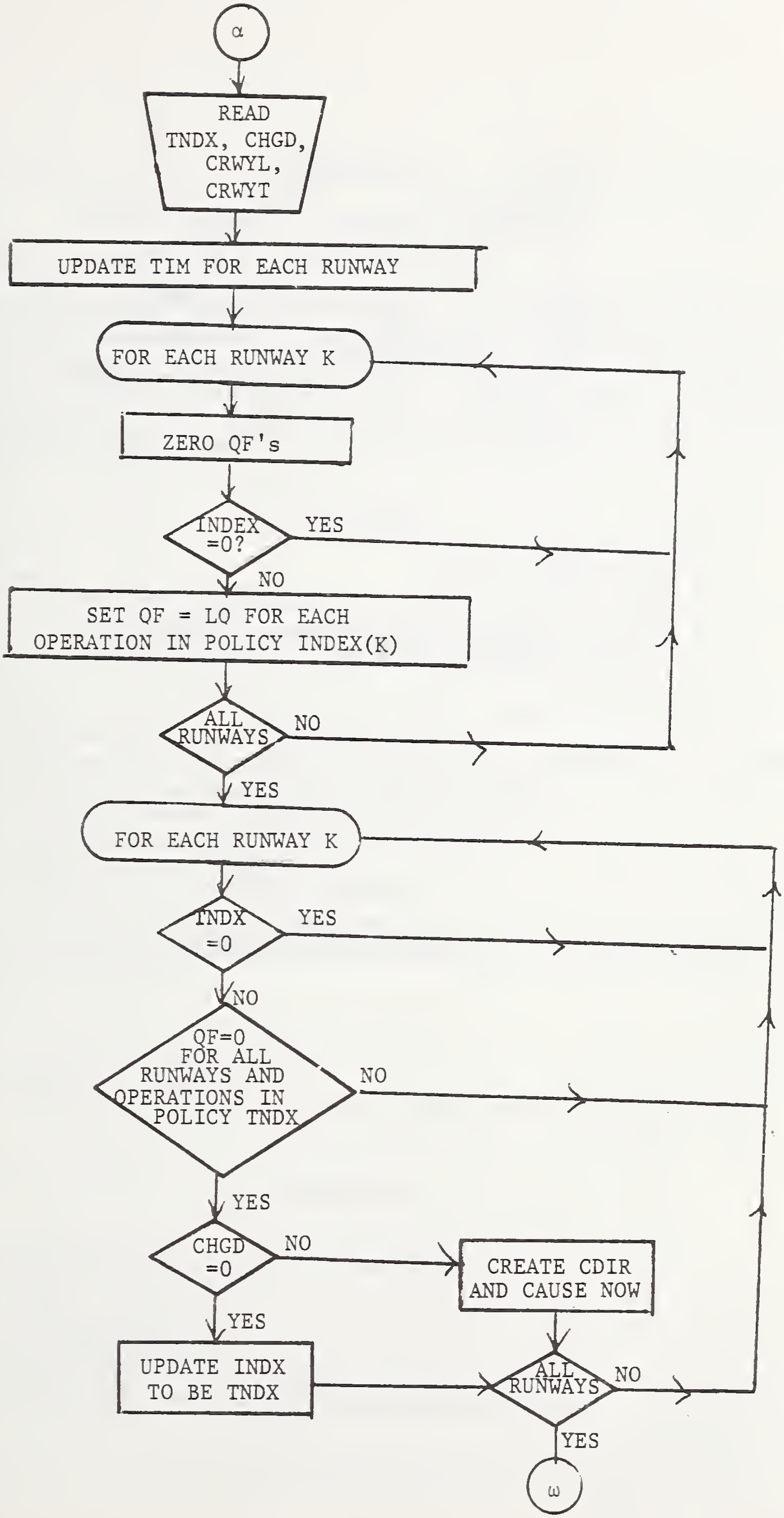

FIGURE B.11
Flowchart of Event CHGOP

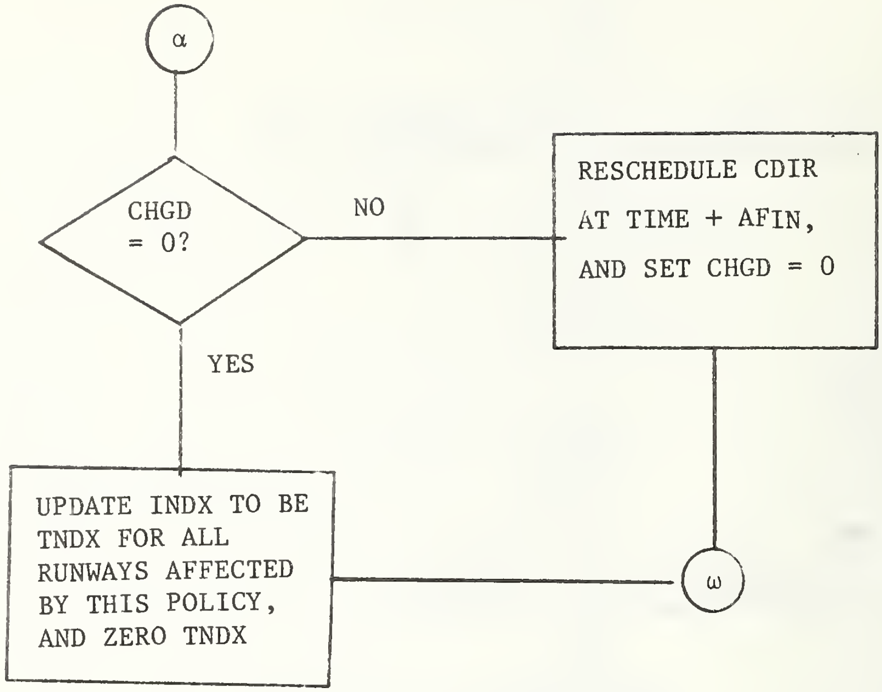

FIGURE B. 12

Flowchart of Event CDIR

APPENDIX C

MODEL ELEMENTS: ROUTINES, VARIABLES AND ARRAYS, ENTITIES, AND SETS

This appendix is divided into two parts. The first lists each of the model's routines, corresponding to events and functions, and provides a phrase describing what each does. The second section lists the names and descriptions of variables used in the model. The variables are listed under the SIMSCRIPT headings of: entities, arrays, attributes of event notices, temporary entities, attributes of temporary entities, and sets.

C.1 Routines

Exogenous Events

1. BEGIN - starts the simulation
2. EXGEN - creates explicitly generated flights
3. CHGOP - initiates an operating policy change

Endogenous Events

1. GEN - creates flights in a Poisson manner
2. NXTOP - finds the next operation (landing or takeoff) for a runway
3. LAND - creates tieups resulting from a landing
4. TOFF - creates tieups resulting from a takeoff
5. FTIUP - destroys tieups no longer in force
6. ENDS - prints final output
7. CHOUR - updates current hour
8. PRINT - records delay and throughput
9. CDIR - accomplishes policy changes, taking into account runway-direction changes

Functions

1. PTYPE - picks an aircraft type
2. PRWAY - picks a runway
3. FREER - finds the first time the current operation can proceed

C.2 Variables

Entities

1. O - operation (1) takeoff, (2) landing
2. RW - runway
3. TYP - aircraft type
4. DX - operating policy
5. H - hour
6. SLOT - positions for printing the delay profile

Variables and Arrays

1. LAMBD(0) - Poisson distribution parameter, the average time (in hours) between operations
2. OPER(RW) - operational procedure
   (1) takeoffs only
   (2) landings only
   (3) dual use, alternate operations
   (4) dual use, landings take precedence
   (5) dual use, operation sequence user-provided
   (6) more than one runway operated together, operation/runway sequence user-provided
3. DOM(RW) - distance from the outer marker to the runway threshold
4. NPT(RW) - greater than zero if the runway RW interferes with others
5. FLYOM(TYP) - time to fly from handoff to the outer marker
6. SQRW(DX, NSQRW(DX)) - sequence of runways used for policy DX
7. VLAND(TYP) - landing speed
8. VTOFF(TYP) - liftoff speed
9. ROTL(TYP) - runway occupancy time on landing
10. ROTT(TYP) - runway occupancy time on takeoff
11. VTAXI - turnoff speed for landings
12. DAFIX - distance from departure/arrival fix to the runway threshold
13. SEPLL(TYP_i,TYP_j) - interlanding separation required between a TYP_i aircraft and a following TYP_j aircraft
14. SEPTL - separation required between a takeoff and following landing
15. CALIN - minimum time between the generation of a takeoff and clearance to leave its gate
16. CTYPE (0, TYPE) - cumulative distribution of aircraft mix
17. CRWYT(RW, TYP) - cumulative distribution of runway use for takeoff
18. CRWYL(RW, TYP) - cumulative distribution of runway use for landing
19. SQOP(DX, NSQOP(DX)) - operation sequence for policy DX
20. NEXT(DX) - is 0 if the next operation has not been scheduled, non-zero otherwise
21. LAST(DX) - index of latest operation used in the sequence for policy DX
22. DINT(RW_i, RW_j) - distance from the end of RW_i to its intersection with RW_j
23. TPT(RW, NTPT(RW)) - type of tieup caused by an operation on runway RW
    (1) to maintain interlanding separation
    (2) to maintain a landing separated from a preceding departure
    (3) to maintain a departure separated from a following landing
    (4) to maintain departure separation between completely dependent runways using the separations in SEPTT
    (5) to maintain departure separation on semi-dependent runways using the separations in SEP2
    (6) to maintain separation on intersecting runways
24. RPT(RW, NRPT(RW)) - runway tied up as a result of an operation on RW. Note that RPT and TPT together describe the interference between runways; RPT tells which runway is interfered with and TPT tells how.
25. TDMIN(RW) - minimum time between a takeoff's leaving its gate and starting its roll
26. SEPTT(TYP_i, TYP_j) - minimum time separation between a takeoff of type TYP_i and a following takeoff of TYP_j

27. SEP2(TYP_i, TYP_j) - similar to SEPTT for a takeoff on one runway following a takeoff on another runway
28. IHOUR - current hour
29. NARR(H) - number of landings generated
30. NDEP(H) - number of takeoffs generated
31. NLAND(H) - number of landings performed
32. NTOFF(H) - number of takeoffs performed
33. DELT(H) - total takeoff delay
34. DELL(H) - total landing delay
35. TBEG - time the accounting for delay starts
36. TEND - time the simulation ends
37. GENN(O) - the identity of the GEN currently scheduled for operation O
38. TDRW(RW,O) - total delay for operation type O on runway RW
39. HDRW(RW,O) - hourly delay for operation type O on runway RW
40. TNRW(RW,O) - total number of operations of type O on runway RW
41. HNRW(RW,O) - hourly number of operations of type O on runway RW
42. INITR - random number seed
43. CAP - is 0 for only throughput printout, 1 for both delay and throughput
44. INDX(RW) - policy used for runway RW
45. TNDX(RW) - policy RW will use as soon as the changeover can be effected
46. CHGD(RW) - is 1 if the new policy for RW involved a change in direction from the previous policy, 0 if not
47. AFIN(RW) - the time required for a runway direction change
48. QF(RW,O) - used when a policy is being changed; is 0 if this runway can accept a new policy, and otherwise is the last FLT, in the queue for operation O on runway RW, which is to occur before the policy change
49. NDLAY(H,SLOT) - the number of aircraft in hour H delayed between SLOT*(INC-2) and SLOT*(INC-1) minutes. (The last position contains all delayed over (NSLOT-2)*INC minutes, and the first position all occurring early or on time.)
50. INC - interval-length for the delay profile
51. IDT(SLOT) - daily totals of NDLAY
52. DTIM - time of latest policy change
53. TIM(RW,O) - length of time period during which runway RW handled operation O.

Attributes of Event Notices

1. RWAY - runway
2. OP - operation
3. PT - point tied up
   (1) outer marker
   (2) runway threshold
   (3) end of the runway
4. DLAY - delay for the current flight

Temporary Entities

1. FLT - flight
2. TIEUP

Attributes of Temporary Entities

1. TYPE(FLT) - aircraft type
2. TIN(FLT) - first time FLT can cross outer marker or leave its gate
3. TMIN(TIEUP) - beginning of tieup interval
4. TMAX(TIEUP) - end of tieup interval

Sets

1. Q(RW,O) - landing and takeoff queues
2. OMTI(RW) - tieups in force at the outer marker
3. THTI(RW) - tieups in force at the runway threshold
4. ERTI(RW) - tieups in force at the end of the runway

APPENDIX D

REVISED INPUT FORMATS

D.1 Revised Preprocessor Input Formats

Card No.	Column Nos.	Variable	No. Decimal Places	FORTRAN Format
1	1 - 7	TBEG - beginning of simulation	2	F7.2
	8 - 14	TEND - end of simulation	2	F7.2
2	1 - 18	INPUT (1 - 6), 3 columns	-	6A3
	19	print indicator (0 = throughput, 1 = both delay and throughput)	-	I1
	20 - 31	random number seed	-	O12
GROUP I				
one per type	1 - 3	number of type ($\leq$ 10)	0	I3
	4 - 10	aver. landing speed (knots)	2	F7.2
	11 - 17	aver. takeoff speed (knots)	2	F7.2
	18 - 24	aver. runway occupancy time - landing - (seconds)	2	F7.2
	25 - 31	aver. runway occupancy time - takeoff - (seconds)	2	F7.2
#types + 1		end-of-file		
#types + 2	1 - 7	aver. turn-off speed, all types	2	F7.2

Card No.	Column Nos.	Variable	No. Decimal Places	FORTRAN Format
GROUP II				
1	6 per type	decimal fraction of take-off mix, of each type	4	12F6.4
2	same	dec. frac. of landing mix of each type	4	12F6.4
GROUP III				
1,2	6 per hour	number of planes taking off per hour	1	12F6.1
3,4	same	# planes landing per hour	1	12F6.1
GROUP IV				
1	1 - 7	required separation between an arrival and a departure (naut. mi.)	2	F7.2
2 through $\frac{NTYPxNTYP}{10}$	7 per type pair	required separation between landing aircraft (naut. mi)	2	10F7.2
next $\frac{NTYPxNTYP}{10}$	7 per type pair	required separation between takeoffs on the same runway (min.)	2	10F7.2
next $\frac{NTYPxNTYP}{10}$	7 per type pair	required separation between takeoffs on different runways (min.)	2	10F7.2
GROUP V				
one per runway	1 - 2	number of runways (1 - 9)	0	I2
	3 - 6	heading of runway	0	I4
	7 - 8	left/right designation	-	A2
	9 - 12	policy to be used by this runway	0	I4

Card No.	Column Nos.	Variable	No. Decimal Places	FORTRAN Format
	13 - 19	distance to outer marker (naut. miles)	2	F7.2
#rw+1		end-of-file		
two per policy	1 - 3	policy number	0	I3
	4 - 6	operation code: 1-takeoffs only, 2-landings only, 3-both, alternating 4-both, landings preferred 5-both, sequence provided 6-both, sequence provided for several runways	0	I3
	7 - 9	number of operations in sequence	0	I3
	3 per operation in sequence	operation sequence	0	20I3
(second card of policy pair)	1 - 3	policy number	0	I3
	4 - 9	blank		
	3 per operation in sequence	runway on which operation is to occur	0	20I3
2*policies + 1		end-of-file		
one per runway	7 per type	time, in minutes, for each type to fly from handoff to outer marker	2	10F7.2
one per inter-section	1 - 2	first runway number	0	I2
	3 - 4	second runway number	0	I2

Card Nos.	Column Nos.	Variable	No. Decimal Places	FORTRAN Format
	5 - 12	distance from end of first RW to intersection (feet)	0	F8.0
	13 - 20	distance from end of second RW to intersection (feet)	0	F8.0
#intersections +1		end-of-file		
one per interference	1 - 2	first runway	0	I2
	3 - 4	second runway	0	I2
	5 - 6	interference code: 1 - simultaneous departures are permitted, given divergence, but arr/arr is prohibited, 2 - all simultaneous operations prohibited.	0	I2
# interferences +1		end-of-file		
GROUP VI				
one per type	6 per runway	decimal fraction of all takeoffs of type which use each runway, followed by decimal fraction of all landings of type which use each runway	4	12F6.4

D.2 Revised Input Formats for Exogenous Events

D.2.1 FLIGHT GENERATION

CARD NO.	COLUMNS	CONTAIN
1	3	the number 2
	6 - 7	the hour the flight enters the system
	9 - 10	the minute of that hour
	11 - 12	the second of that minute
	13 - 14	1 if flight is a takeoff, 2 if a landing
	15 - 16	the runway to be used by this flight
	17 - 18	the aircraft type for this flight

D.2.2 POLICY CHANGE

CARD NO.	COLUMNS	CONTAIN
1	3	the number 3
	6 - 7	the hour the policy change is to be initiated
	9 - 10	the minute of that hour
	11 - 12	the second of that minute
for each runway	3 - 4	new policy number to be used
	5 - 6	1 if the runway direction is changed, 0 otherwise
for each runway and type	5 - 11 (4 decimal places)	CRWYT
	12 - 18	CRWYL

APPENDIX E

PROGRAM LISTINGS

E.1 Listing of the Preprocessor

```
C     THIS PROGRAM IS A PREPROCESSOR WHICH READS IN THE DATA AND
C     PUTS IT INTO PROPER FORM FOR USE BY THE SIMULATION PROGRAM.
      PARAMETER KRW=20,KTYP=10,KSEQ=20,KO=2,KTPT=20,KNDX=20
      INTEGER OPER(KNDX),RPT(KRW,KTPT),TPT(KRW,KTPT),
     1  SQOP(KNDX,KSEQ),SQRW(KNDX,KSEQ),RW(KRW),INDX(KRW)
      REAL LAMBD(KO,24)
      DIMENSION DOM(KRW),NPT(KRW),FLYOM(KTYP,KRW),VLAND(KTYP),ROTL(KTYP)
     1,VTOFF(KTYP),ROTT(KTYP),PTYPE(KO,KTYP),PRWYT(KTYP,KRW),LAST(KRW),
     2   PRWYL(KTYP,KRW),NSQOP(KRW),PINT(KRW,KRW),INPUT(8),TDMIN(KRW),
     3SEP2(KTYP,KTYP),SEPTT(KTYP,KTYP),INTER(KRW,KRW),CALIN(KRW),N(100),
     4 IHEAD(KRW),ILR(KRW),AFIN(KRW)
      DIMENSION  SEPLL(KTYP,KTYP)
C     ------------------
C     TBEG,TEND ARE TIMES OF BEGINNING AND END OF SIMULATION
C     EXAMPLES ARE 0.00 FOR MIDNIGHT AND 17.30 FOR 5.30 P.M.
C     ------------------
      READ(5,705)TBEG,TEND
  705 FORMAT(10F7.2)
      WRITE(6,500)TBEG,TEND
  500 FORMAT('1THIS SIMULATION RUNS FROM'F6.2,' TO'F6.2///)
      TBEG=AINT(TBEG)+(TBEG-AINT(TBEG))/60.
      TEND=AINT(TEND)+(TEND-AINT(TEND))/60.
      IF (TBEG.GT.0.) GO TO 1
      TBEG=TBEG+24.
      TEND=TEND+24.
1     IF (TEND.LE.TBEG) TEND=TEND+24.
      IBEG=TBEG-1.
      IHOUR=MOD(IBEG,24)+1
      NH=TEND-TBEG+.99
      ND=-1
      IF (NH.LT.24) GO TO 2
      II=1
      JJ=24
      GO TO 4
2     II=IHOUR
      IEND=TEND-.01
      JJ=MOD(IEND,24)+1
      IF (JJ.LT.II) ND=JJ
C     ------------------
C     INPUT(I) - LEAVE BLANK IF ITH DATA GROUP WILL BE SUPPLIED BY USER
C               ANYTHING ELSE WILL CAUSE PROGRAM TO SUPPLY STANDARD DATA
C     DATA GROUPS ARE - 1) NUMBER AND DESCRIPTION OF AIRCRAFT TYPES
C                       2) MIX OF AIRCRAFT TYPES
C                       3) LANDING AND TAKEOFF RATES, BY HOUR
C                       4) SEPARATION REQUIREMENTS
```

```
C                         5) DESCRIPTION OF AIRPORT AND ITS OPERATION
C                         6) FRACTION OF TYPES USING EACH RUNWAY AND
C                            DEPARTURE PATH
C     ICAP - FLAG USED TO CONTROL PRINTING OF DELAY OUTPUT
C            (0 = ONLY THROUGHPUT,  1 = BOTH THROUGHPUT AND DELAY)
C     INITR - INITIAL RANDOM NUMBER SEED (12 OCTAL DIGITS)
C     ------------------
4     READ (5,730) (INPUT(I),I=1,6),ICAP,INITR
730   FORMAT (6A3,I1,O12)
C
C   ***********************
C   *  INPUT DATA GROUP 1 *
C   ***********************
C
C     ------------------
C     NTYPE - NUMBER OF TYPES
C     VTOFF(I) - TAKEOFF SPEED OF TYPE I, IN KNOTS
C     VLAND(I) - LANDING SPEED OF TYPE I, IN KNOTS
C     ROTL(I) - RUNWAY OCCUPANCY TIME ON LANDINGS FOR TYPE I, IN SECONDS
C     ROTT(I) - SAME FOR TAKEOFFS
C     VTAXI - AVERAGE TURNOFF SPEED FOR ALL TYPES
C     ------------------
      IF(INPUT(1).EQ.'   ')GO TO 5
C     ------------------
C     STANDARD TYPE INPUT:  TYPE 1 - HEAVY AIRCRAFT
C                           TYPE 2 - SMALL PROP AIRCRAFT
C                           TYPE 3 - CATEGORY 3'S
C     DATA FROM VALUES OBTAINED AT JFK
C     ------------------
      DATA NTYPE/3/VTAXI/20./
      DATA (VLAND(I),VTOFF(I),ROTL(I),ROTT(I),I=1,3)/
     1 124.,120.,55.,33.,110.,90.,40.,27.,120.,120.,50.,32./
      GO TO 10
    5 READ(5,725,END=6)NTYPE,VLAND(NTYPE),VTOFF(NTYPE),
     1                 ROTL(NTYPE),ROTT(NTYPE)
  725 FORMAT(I3,4F7.2)
      GO TO 5
    6 READ(5,705)VTAXI
10    DO 7 I=1,NTYPE
      ROTL(I)=ROTL(I)/3600.
    7 ROTT(I)=ROTT(I)/3600.
C
C   ***********************
C   *  INPUT DATA GROUP 2 *
C   ***********************
C
C     ------------------
C     PTYPE(1,I) - THE FRACTION OF TOTAL TAKEOFFS WHICH ARE OF TYPE I
C     PTYPE(2,I) - SAME FOR LANDINGS
C     ------------------
      IF(INPUT(2).EQ.'   ')GO TO 15
C     ------------------
C     STANDARD TYPE MIX - 5%HEAVIES,17% SMALL, 78% CATEGORY 3'S
C     ------------------
      DATA ((PTYPE(I,J),J=1,3),I=1,2)/.05,.22,1.0,.05,.22,1.0/
      GO TO 30
   15 DO 16 I=1,2
      READ(5,710)(PTYPE(I,J),J=1,NTYPE)
```

```
 710 FORMAT(12F6.4)
  16 CONTINUE
     DO 25 I=1,2
     DO 20 J=2,NTYPE
  20 PTYPE(I,J)=PTYPE(I,J-1)+PTYPE(I,J)
     IF(INT((PTYPE(I,NTYPE)+.01)*100.).NE.100)WRITE(6,800)I
 800 FORMAT(' WARNING - PROBABILITIES OF ALL TYPES FOR OPERATION',I2,
    1' (1-LANDING, 2-TAKEOFF) DO NOT SUM TO ONE')
  25 CONTINUE
C
C   ***********************
C   *  INPUT DATA GROUP 3 *
C   ***********************
C
C     -------------------
C     LAMBD(1,I) - AVERAGE NUMBER OF TAKEOFFS DURING ITH HOUR OF THE DAY
C     LAMBD(2,I) - SAME FOR LANDINGS
C     -------------------
  30 IF(INPUT(3).EQ.'    ')GO TO 35
C     -------------------
C     STANDARD DEPARTURE AND ARRIVAL RATES ARE 200 AND 100 PER HOUR
C     RESPECTIVELY  (FOR USE IN CAPACITY RUNS)
C     -------------------
     DO 31 I=1,24
     LAMBD(1,I)=1./200.
     LAMBD(2,I)=1./100.
31   CONTINUE
     GO TO 40
  35 IF(ND.GT.0)GO TO 37
     DO 36 I=1,2
     READ(5,720)(LAMBD(I,J),J=II,JJ)
 720 FORMAT(12F6.1)
     DO 36 J=1,24
     IF(LAMBD(I,J).LE.0.)GO TO 351
     LAMBD(I,J)=1./LAMBD(I,J)
     GO TO 36
 351 LAMBD(I,J)=9.999
  36 CONTINUE
     GO TO 40
  37 DO 38 I=1,2
     READ(5,720)(LAMBD(I,J),J=IHOUR,24),(LAMBD(I,J),J=1,ND)
     DO 38 J=1,24
     IF(LAMBD(I,J).LE.0.)GO TO 371
     LAMBD(I,J)=1./LAMBD(I,J)
     GO TO 38
 371 LAMBD(I,J)=9.999
  38 CONTINUE
C
C   ***********************
C   *  INPUT DATA GROUP 4 *
C   ***********************
C
C
C     -------------------
C     SEPLL - RADAR SEPARATION REQUIRED BETWEEN AIRCRAFT ON SAME PATH
C     SEPTL - RADAR SEPARATION REQUIRED BETWEEN A LANDING A/C AND AN A/C
C             TAKING OFF FROM THE SAME RUNWAY
C     ALL  DISTANCES ARE IN NAUTICAL MILES.
```

```
C
C     SEP2  - TIME SEPARATION REQUIRED BETWEEN AIRCRAFT DEPARTING ON
C             DIFFERENT RUNWAYS
C     ------------------
   40 IF(INPUT(4).EQ.'    ')GO TO 45
      DAFIX=4.
C     ------------------
C     STANDARD SEPARATION REQUIREMENTS
C     ------------------
      SEPTL=2.
      DO 41  J=1,NTYPE
      SEPLL(1,J)=5.
      DO 41  I=2,NTYPE
41    SEPLL(I,J)=3.
      SEPLL(1,1)=4.
139   DO 140  I=1,NTYPE
      DO 140  J=1,NTYPE
      SEPTT(I,J)=20./3600.+ROTT(I)
140   SEP2(I,J)=ROTT(I)
      DO 1401  J=2,NTYPE
1401  SEPTT(1,J)=2./60.+ROTT(1)
      SEPTT(1,1)=2./60.
      GO TO 50
45    READ (5,705) SEPTL
      READ (5,705) ((SEPLL(I,J),I=1,NTYPE),J=1,NTYPE)
      READ (5,705) ((SEPTT(I,J),I=1,NTYPE),J=1,NTYPE)
      READ (5,705) ((SEP2(I,J),I=1,NTYPE),J=1,NTYPE)
C    ***********************
C    *  INPUT DATA GROUP 5 *
C    ***********************
C
C     ------------------
C     IHEAD(I) - THE HEADING OF RUNWAY I
C     ILR(I) - FOR PARALLEL RUNWAYS, THE LEFT OR RIGHT DESIGNATION
C     FOR EXAMPLE, IF RUNWAY 2 IS 31R, IHEAD(2)=31 AND ILR(2)=R
C     INDX(I) - NUMBER OF THE OPERATING POLICY TO BE USED ON RUNWAY I
C     OPER(J) - OPERATING CODE FOR POLICY NUMBER J
C     SOOP(J,K) - SEQUENCE OF OPERATIONS FOR POLICY J (1 = TAKEOFF,
C                 2 = LAND).  THE SEQUENCE IS REPEATED OVER AND OVER.
C     NSOOP(J) - NUMBER OF OPERATIONS IN POLICY J
C     SORW(J,K) - THE RUNWAY UPON WHICH THE K-TH OPERATION IN POLICY J
C                 IS TO OCCUR.
C               CODES ARE 1- TAKEOFFS ONLY, 2- LANDINGS ONLY
C                         3-DUAL USE, ALTERNATING OPERATIONS
C                         4-DUAL USE, LANDINGS TAKE PRECEDENCE
C     DOM(I) - DISTANCE TO OUTER MARKER FOR RUNWAY I
C     FLYOM(I,J)- TIME, IN MINUTES, FOR A TYPE I A/C TO FLY FROM HANDOFF
C                  TO OUTER MARKER OF RUNWAY J
C     DINT(I,J) - DISTANCE FROM END OF RUNWAY I TO ITS INTERSECTION
C                 WITH RUNWAY J, IN FEET
C     INTER(I,J) - INTERFERENCE CODE FOR RUNWAYS I AND J
C                  CODES ARE  1- LANDINGS ON I AND J INTERFERE AND
C                                MUST BE SEPARATED, BUT SIMULTANEOUS
C                                TAKEOFFS ARE PERMITTED IF THEY DIVERGE.
C                             2- NO SIMULTANEOUS OPERATIONS PERMITTED
C                  IF NEITHER, COMPLETE INDEPENDENCE IS ASSUMED.
C     ------------------
```

```
   50 IF(INPUT(5).EQ.'    ')GO TO 55
C        -------------------
C        STANDARD DATA IS FOR SINGLE RUNWAY WITH ALTERNATING OPERATIONS
C        -------------------
         DATA NRW/1/IHEAD(1)/15/ILR(1)/2H  /OPER(1)/3/DOM(1)/5./
        1  (FLYOM(J,1),J=1,3)/10.,13.,10./DINT(1,1)/0./INTER(1,1)/0./
        2  MIN/2/(SOOP(1,I),I=1,10)/1,2,8*0/(SQRW(1,I),I=1,10)/1,1,8*0/
        3  LAST(1)/1/INDX(1)/1/MNDX/1/
         GO TO 572
55       NRW=0
551      READ (5,735,END=552) I,IHEAD(I),ILR(I),INDX(I),DOM(I)
  735 FORMAT(I2,I4,A2,I4,F7.2)
         NRW=NRW+1
         GO TO 551
552      DO 553 I=1,KNDX
         LAST(I)=1
553      OPER(I)=0
         MNDX=0
554      READ (5,615,END=557) NDX,OPER(NDX),MIN,(SOOP(NDX,I),I=1,MIN)
         NSOOP(NDX)=MIN
615      FORMAT (23I3)
         READ (5,616) (SQRW(NDX,I),I=1,MIN)
616      FORMAT (9X,20I3)
         IF (NDX.GT.MNDX) MNDX=NDX
         GO TO 554
557      DO 556 K=1,NRW
         I=INDX(K)
         IF (I.EQ.0) GO TO 556
         IF (OPER(I).GT.0) GO TO 556
         WRITE (6,590) I,K
590      FORMAT ('0WARNING - NO POLICY PROVIDED FOR INDEX',I5,2X,'FOR RUNWA
        1Y',I5)
556      CONTINUE
         DO 56 I=1,NRW
         READ(5,705)(FLYOM(J,I),J=1,NTYPE)
         DO 56 J=1,NRW
         DINT(I,J)=0.
         INTER(I,J)=0.
   56 CONTINUE
   57 READ(5,715,END=571)I,J,DINT(I,J),DINT(J,I)
  715 FORMAT(2I2,2F8.0)
      GO TO 57
  571 READ(5,700,END=572)I,J,INTER(I,J)
  700 FORMAT(10I2)
      GO TO 571
  572 DO 59 I=1,NRW
      DO 58 J=1,NTYPE
   58 FLYOM(J,I)=FLYOM(J,I)/60.
      DO 59 J=1,NRW
   59 DINT(I,J)=DINT(I,J)/6076.
      DO 60 I=1,NRW
      DO 60 J=1,NRW
      IF(INTER(I,J).EQ.0)GO TO 60
      INTER(J,I)=INTER(I,J)
   60 CONTINUE
      DO 90 I=1,NRW
      K=0
      DO 89 J=1,NRW
```

```
      IF(INTFR(I,J).EQ.0)GO TO 80
      I1=INDX(I)
      II=4
      IF (I1.NE.0) II=OPER(I1)
      J1=INDX(J)
      JJ=4
      IF (J1.NE.0) JJ=OPER(J1)
      IF (II.LT.2.OR.JJ.LT.2) GO TO 65
      K=K+1
      RPT(I,K)=J
      TPT(I,K)=1
65    IF (II.EQ.2.OR.JJ.EQ.2) GO TO 70
      K=K+1
      RPT(I,K)=J
      TPT(I,K)=4
      IF(INTER(I,J).EQ.1)TPT(I,K)=5
70    IF (II.EQ.2.OR.JJ.EQ.1) GO TO 75
      K=K+1
      RPT(I,K)=J
      TPT(I,K)=3
75    IF (II.EQ.1.OR.JJ.EQ.2) GO TO 80
      K=K+1
      RPT(I,K)=J
      TPT(I,K)=2
   80 CONTINUE
      DO 85 J=1,NRW
      IF(DINT(I,J).LE.0.)GO TO 85
      K=K+1
      RPT(I,K)=J
      TPT(I,K)=6
   85 CONTINUE
      NPT(I)=K
      K=K+1
      DO 86 L=K,KTPT
      RPT(I,L)=0
      TPT(I,L)=0
   86 CONTINUE
   90 CONTINUE
C
C    **********************
C    *  INPUT DATA GROUP 6 *
C    **********************
C
C     ------------------
C     PRWYT(I,J) - THE FRACTION OF ALL TAKEOFFS OF TYPE I A/C
C     WHICH USE RUNWAY J
C     PRWYL(I,J) - THE SAME FOR LANDINGS
C     ------------------
  110 IF(INPUT(6).EQ.'    ')GO TO 115
C     ------------------
C     STANDARD RUNWAY USAGE HAS ALL AIRCRAFT OPERATIONS ON RUNWAY 1
C     ------------------
      DATA (PRWYT(I,1),I=1,3)/3*1./(PRWYL(I,1),I=1,3)/3*1./
      GO TO 145
  115 DO 120 J=1,NTYPE
  120 READ(5,710)(PRWYT(J,I),I=1,NRW),(PRWYL(J,I),I=1,NRW)
      DO 122 I=1,NRW
      I1=INDX(I)
```

```
      II=4
      IF (I1.GT.0) II=OPER(I1)
      DO 122 J=1,NTYPE
      IF (PRWYT(J,I).GT.0.AND.II.EQ.2) WRITE (6,830) J,I
  830 FORMAT(' WARNING - THERE IS A POSITIVE PROBABILITY THAT A TYPE',
     1I2,' AIRCRAFT WILL TAKE OFF FROM'/12X,'RUNWAY',I2,', WHICH HANDLES
     2 LANDINGS ONLY')
      IF (PRWYL(J,I).GT.0.AND.II.EQ.1) WRITE (6,840) J,I
  840 FORMAT(' WARNING - THERE IS A POSITIVE PROBABILITY THAT A TYPE',
     1I2,' AIRCRAFT WILL LAND ON '/12X,'RUNWAY',I2,', WHICH HANDLES TAKE
     2OFFS ONLY')
  122 CONTINUE
1241  IF (NRW.EQ.1) GO TO 145
      DO 130 I=1,NTYPE
      DO 125 J=2,NRW
      PRWYL(I,J)=PRWYL(I,J-1)+PRWYL(I,J)
  125 PRWYT(I,J)=PRWYT(I,J-1)+PRWYT(I,J)
      IF(INT((PRWYL(I,NRW  )+.01)*100.).NE.100)WRITE(6,810)I
  810 FORMAT(' WARNING - PROBABILITIES OF A TYPE',I2,' AIRCRAFT LANDING
     1ON ALL RUNWAYS DO NOT SUM TO ONE')
      IF(INT((PRWYT(I,NRW  )+.01)*100.).NE.100)WRITE(6,820)I
  820 FORMAT(' WARNING - PROBABILITIES OF A TYPE',I2,' AIRCRAFT TAKING
     1OFF FROM ALL RUNWAYS DO NOT SUM TO ONE')
  130 CONTINUE
145   DO 150 I=1,100
  150 N(I)=I
      DO 95 I=1,NRW
      TDMIN(I)=(DOM(I)/VLAND(1))*PTYPE(2,1)
      AFIN(I)=TDMIN(I)+ROTT(1)*PTYPE(1,1)
      DO 95 J=2,NTYPE
      TDMIN(I)=(DOM(I)/VLAND(J))*(PTYPE(2,J)-PTYPE(2,J-1))+TDMIN(I)
95    AFIN(I)=TDMIN(I)+ROTT(J)*PTYPE(1,J)
      DO 100 I=1,NRW
      CALIN(I)=FLYOM(I,1)*PTYPE(2,1)
      DO 100 J=2,NTYPE
  100 CALIN(I)=FLYOM(I,J)*(PTYPE(2,J)-PTYPE(2,J-1))+CALIN(I)
C
C    **************************
C    * WRITE SIMULATION INPUT *
C    **************************
C
      XINC=5.
      L=0
      M=8
      WRITE (M,899)
899   FORMAT ('1',9X,'67',4X,'60',4X,'60')
      WRITE(M,900)N(1),N(2)
      WRITE(M,900)N(2),NRW
      WRITE(M,900)N(3),NTYPE
      WRITE (M,900) N(4), MNDX
      WRITE(M,900)N(5),N(24)
      WRITE (M,920) N(6),MNDX,N(4),(OPER(I),I=1,MNDX)
      WRITE(M,930)N(7),NRW,N(2),(DOM(I),I=1,NRW)
      WRITE(M,920)N(8),NRW,N(2),(NPT(I),I=1,NRW)
      DO 155 I=1,NRW
      IF(NPT(I).EQ.0)NPT(I)=1
  155 CONTINUE
      WRITE(M,940)N(9),NTYPE,N(3),NRW,N(2),((FLYOM(J,I),I=1,NRW),
```

```
     1J=1,NTYPE)
      WRITE (M,960) N(10),MNDX,N(4),((SQRW(K,I),I=1,KSEQ),NSQOP(K),
     1  K=1,MNDX)
      WRITE(M,930)N(11),NTYPE,N(3),(VLAND(I),I=1,NTYPE)
      WRITE(M,930)N(12),NTYPE,N(3),(VTOFF(I),I=1,NTYPE)
      WRITE(M,930)N(13),NTYPE,N(3),(ROTL(I),I=1,NTYPE)
      WRITE(M,930)N(14),NTYPE,N(3),(ROTT(I),I=1,NTYPE)
      WRITE(M,910)N(15),VTAXI
      WRITE(M,910)N(16),N(2)
      WRITE (M,945) N(17),NTYPE,N(3),NTYPE,N(3),((SEPLL(I,J),J=1,NTYPE),
     1  I=1,NTYPE)
      WRITE(M,910)N(18),SEPTL
      WRITE(M,930)N(19),NRW,N(2),(CALIN(I),I=1,NRW)
      WRITE(M,940)N(20),N(2),N(1),NTYPE,N(3),((PTYPE(I,J),J=1,NTYPE),
     1I=1,2)
      WRITE(M,940)N(21),NTYPE,N(3),NRW,N(2),((PRWYT(I,J),J=1,NRW),
     1I=1,NTYPE)
      WRITE(M,940)N(22),NTYPE,N(3),NRW,N(2),((PRWYL(I,J),J=1,NRW),
     1I=1,NTYPE)
      WRITE (M,960) N(23),MNDX,N(4),((SQOP(K,I),I=1,KSEQ),NSQOP(K),
     1  K=1,MNDX)
      WRITE (M,950) N(24),N(24),N(1),MNDX,N(4)
      WRITE (M,920) N(25),MNDX,N(4),(LAST(I),I=1,MNDX)
      WRITE(M,940)N(26),NRW,N(2),NRW,N(2),((DINT(I,J),J=1,NRW),I=1,NRW)
      WRITE(M,950)N(27),N(28),N(2),NRW,N(2),N(2),N(1)
      WRITE (M,960) N(29),NRW,N(2),((RPT(I,J),J=1,KTPT),NPT(I),I=1,NRW)
      WRITE (M,960) N(30),NRW,N(2),((TPT(I,J),J=1,KTPT),NPT(I),I=1,NRW)
      WRITE(M,930)N(31),NRW,N(2),(TDMIN(I),I=1,NRW)
      WRITE (M,940) N(32),NTYPE,N(3),NTYPE,N(3),((SEPTT(I,J),J=1,NTYPE),
     1  I=1,NTYPE)
      WRITE(M,950)N(33),N(38),N(1),N(24),N(5)
      WRITE(M,910)N(39),TBEG
      WRITE(M,950)N(40),N(45),N(1),NRW,N(2)
      WRITE(M,910)N(46),TEND
      WRITE(M,940)N(47),N(2),N(1),N(24),N(5),((LAMBD(I,J),J=1,24),I=1,2)
      WRITE(M,900)N(48),IHOUR
      WRITE (M,940) N(49),NTYPE,N(3),NTYPE,N(3),(( SEP2(I,J),J=1,NTYPE),
     1  I=1,NTYPE)
      WRITE (M,950) N(50),N(50),N(1),N(2),N(1)
      WRITE (M,950) N(51),N(54),N(2),NRW,N(2),N(2),N(1)
      WRITE (M,955) N(55),INITP
      WRITE (M,900) N(56),ICAP
      WRITE (M,920) N(57),NRW,N(2),(INDX(I),I=1,NRW)
      WRITE (M,950) N(58),N(59),N(1),NRW,N(2)
      WRITE (M,930) N(60),NRW,N(2),(AFIN(I),I=1,NRW)
      WRITE (M,950) N(61),N(61),N(2),NRW,N(2),N(2),N(1)
      WRITE (M,900) N(62),N(14)
      WRITE (M,950) N(63),N(63),N(2),N(24),N(5),N(14),N(62)
      WRITE (M,910) N(64),XINC
      WRITE (M,950) N(65),N(65),N(1),N(14),N(62)
      WRITE (M,910) N(66),TBEG
      WRITE (M,950) N(67),N(67),N(2),NRW,N(2),N(2),N(1)
      WRITE(M,970)
      WRITE(M,980)N(1),IBEG,L,L
  900 FORMAT(I4,5X,'0 R',I39)
  910 FORMAT(I4,5X,'0 R',37XF7.3)
  920 FORMAT (I4,5X,'1 R',I6,I4,27X,'20(I2)'/(20I2))
  930 FORMAT(I4,5X,'1 R',I6,I4,27X,'10(F8.4)'/(10F8.4))
```

```
  940 FORMAT(I4,5X,'2 P',I6,3I4,5X,'R  F',11X,'12(D1.4)'/(12F6.4))
  945 FORMAT(I4,5X,'2 P',I6,3I4,5X,'R  F',11X,'10(D2.4)'/(10F7.4))
  950 FORMAT(2I4,I2,'  Z',I5,3I4)
955   FORMAT (I4,5X,'0 R',37X,'(012)'/(012))
960   FORMAT (I4,5X,'2 R',I6,I4,18X,'R',8X,'20(I2)'/(20I2,30X,I2))
  970 FORMAT(' ')
  980 FORMAT(I3,I4,I3,I2)
C
C    **************************
C    * PRINT RUN DESCRIPTION *
C    **************************
C
      WRITE(6,505)
  505 FORMAT(//20X'AIRCRAFT DESCRIPTION'//1X'TYPE'15X'SPEEDS (KNOTS)'6X
     1'RUNWAY OCCUPANCY (SECONDS)'/18X'LANDING'4X'LIFTOFF'6X'LANDING'6X
     2'TAKEOFF'//)
      DO 160 I=1,NTYPE
      RROTL=ROTL(I)*3600.
      RROTT=ROTT(I)*3600.
      WRITE(6,510)I,VLAND(I),VTOFF(I),RROTL,RROTT
  510 FORMAT('0'1XI2,15XF4.0,7XF4.0,10XF4.0,9XF4.0)
  160 CONTINUE
      WRITE(6,511)
  511 FORMAT(//5X'TRAFFIC DESCRIPTION'//1X'TYPE'5X'LANDING'4X'TAKEOFF'
     1/12X'MIX'8X'MIX'//)
      A=PTYPE(2,1)*100.
      B=PTYPE(1,1)*100.
      WRITE(6,515)N(1),A,B
  515 FORMAT(2XI2,2(7XF4.0)/)
      DO 165 I=2,NTYPE
      A=(PTYPE(2,I)-PTYPE(2,I-1))*100.
      B=(PTYPE(1,I)-PTYPE(1,I-1))*100.
      WRITE(6,515)I,A,B
  165 CONTINUE
      WRITE(6,520)
  520 FORMAT('1AIRPORT CONFIGURATION')
      WRITE(6,525)NRW
  525 FORMAT(///' NUMBER OF RUNWAYS ='I2)
      DO 190 I=1,NRW
      II=INDX(I)
      IF (II.EQ.0) GO TO 166
      J=OPER(II)
      GO TO (170,175,180,185,186,186),J
  170 WRITE(6,530)I,IHEAD(I),ILR(I)
  530 FORMAT('0RUNWAY'I2,' ('I2,A2,') - TAKEOFFS ONLY')
      GO TO 190
  175 WRITE(6,535)I,IHEAD(I),ILR(I)
  535 FORMAT('0RUNWAY'I2,' ('I2,A2,') - LANDINGS ONLY')
      GO TO 190
  180 WRITE(6,540)I,IHEAD(I),ILR(I)
  540 FORMAT('0RUNWAY'I2,' ('I2,A2,') - DUAL USE, ALTERNATING OPERATIONS
     1')
      GO TO 190
  185 WRITE(6,545)I,IHEAD(I),ILR(I)
  545 FORMAT('0RUNWAY'I2,' ('I2,A2,') - DUAL USE, LANDINGS TAKE PRECEDEN
     1CE')
      GO TO 190
186   MIN=MSOOP(II)
```

```
      DO 189 J=1,NIN
      JJ=SQOP(II,J)
      GO TO (187,188),JJ
187   SQOP(II,J)='DEPART'
      GO TO 189
188   SQOP(II,J)='ARRIVE'
189   CONTINUE
      IF (OPER(II).GT.5) GO TO 191
      WRITE (6,546) I,IHEAD(I),ILR(I),(SQOP(I,J),J=1,NIN)
546   FORMAT ('0RUNWAY',I2,' (',I2,A2,') - DUAL-USE, OPERATION SEQUENCE
     1- '/(2X,10(A6,1X)))
      GO TO 190
191   NIM=0
      DO 194 J=1,NIN
      IF (SQRW(II,J).EQ.I) GO TO 194
      IF (NIM.EQ.0) GO TO 193
      DO 192 JJ=1,NIM
192   IF (SQRW(II,J).EQ.RW(JJ)) GO TO 194
193   NIM=NIM+1
      RW(NIM)=SQRW(II,J)
194   CONTINUE
      IF (NIM.GT.0) GO TO 196
      WRITE (6,546) I,IHEAD(I),ILR(I),(SQOP(I,J),J=1,NIN)
      GO TO 190
196   WRITE (6,547) I,IHEAD(I),ILR(I),(RW(J),J=1,NIM)
547   FORMAT ('0RUNWAY',I2,' (',I2,A2,') - OPERATED WITH RUNWAYS',10I2)
      WRITE (6,548) (SQOP(II,J),SQRW(II,J),J=1,NIN)
548   FORMAT (' OPERATION SEQUENCE'/5(1X,A6,' ON',I2))
      DO 198 J=1,NIN
      IF (SQOP(II,J).EQ.'ARRIVE') SQOP(II,J)=2
198   IF (SQOP(II,J).EQ.'DEPART') SQOP(II,J)=1
      GO TO 190
166   WRITE (6,549) I,IHEAD(I),ILR(I)
549   FORMAT ('0RUNWAY',I2,' (',I2,A2,') - NO POLICY PROVIDED/ NOT USED
     1INITIALLY')
  190 CONTINUE
      DO 195 I=1,NRW
      DO 195 J=I,NRW
      IF(DINT(I,J).LE.0.)GO TO 195
      A=DINT(I,J)*6076.
      B=DINT(J,I)*6076.
      WRITE(6,550)IHEAD(I),ILR(I),IHEAD(J),ILR(J),A,IHEAD(I),ILR(I),B,
     1IHEAD(J),ILR(J)
  550 FORMAT(//'0RUNWAYS'I3,A2,' AND'I3,A2,' INTERSECT AT A POINT'F7.0,
     1' FEET FROM THE'/' END OF RUNWAY'I3,A2,' AND'F7.0,' FEET FROM THE
     2END OF RUNWAY'I3,A2,'.')
  195 CONTINUE
      II=NRW-1
      DO 215 I=1,II
      JJ=I+1
      DO 215 J=JJ,NRW
      IF(INTER(I,J).EQ.0.AND.IHEAD(I).NE.IHEAD(J))GO TO 215
      L=INTER(I,J)+1
      IF(IHEAD(I).NE.IHEAD(J))GO TO 211
      GO TO(200,205,210),L
  200 WRITE(6,555)IHEAD(I),ILR(I),IHEAD(J),ILR(J)
  555 FORMAT(/'0RUNWAYS'I3,A2,' AND'I3,A2,' ARE INDEPENDENT PARALLELS -'
     1/' SIMULTANEOUS OPERATIONS ARE PERMITTED')
```

```
      GO TO 215
  205 WRITE(6,560)IHEAD(I),ILR(I),IHEAD(J),ILR(J)
  560 FORMAT(/'0RUNWAYS'I3,A2,' AND'I3,A2,' ARE SEMI-DEPENDENT PARALLELS
     1 -'/' SIMULTANEOUS ARRIVALS ARE PROHIBITED')
      GO TO 215
  210 WRITE(6,565)IHEAD(I),ILR(I),IHEAD(J),ILR(J)
  565 FORMAT(/'0RUNWAYS'I3,A2,' AND'I3,A2,' ARE DEPENDENT PARALLELS -'/
     1' NO SIMULTANEOUS OPERATIONS ARE PERMITTED')
      GO TO 215
211   GO TO(215,212,213),L
  212 WRITE(6,570)IHEAD(I),ILR(I),IHEAD(J),ILR(J)
  570 FORMAT(/'0RUNWAYS'I3,A2,' AND'I3,A2,' ARE SEMI-DEPENDENT -'/' SIMU
     1LTANEOUS ARRIVALS ARE PROHIBITED')
      GO TO 215
  213 WRITE(6,575)IHEAD(I),ILR(I),IHEAD(J),ILR(J)
  575 FORMAT(/'0RUNWAYS'I3,A2,' AND'I3,A2,' ARE DEPENDENT -'/' NO SIMULT
     1ANEOUS OPERATIONS ARE PERMITTED')
  215 CONTINUE
      DO 402 I=1,NTYPE
      J=NRW
401   PRWYL(I,J)=PRWYL(I,J)-PRWYL(I,J-1)
      PRWYT(I,J)=PRWYT(I,J)-PRWYT(I,J-1)
      J=J-1
      IF (J.GT.1) GO TO 401
402   CONTINUE
      WRITE (6,449)
449   FORMAT ('1 FRACTION OF LANDINGS OF EACH TYPE ON EACH RUNWAY'///)
      WRITE (6,450) (J,IHEAD(J),ILR(J),J=1,NRW)
450   FORMAT (7X,'RUNWAY',5X,7(I1,' (',I2,A2,')',8X))
      WRITE (6,951)
951   FORMAT (2X,'TYPE'/)
      DO 403 I=1,NTYPE
      WRITE (6,452) I,(PRWYL(I,J),J=1,NRW)
452   FORMAT (3X,I2,3X,7(10X,F6.4))
403   CONTINUE
      WRITE (6,453)
453   FORMAT ('0'///)
      WRITE (6,454)
454   FORMAT ('0 FRACTION OF TAKEOFFS OF EACH TYPE ON EACH RUNWAY'///)
      WRITE (6,450) (J,IHEAD(J),ILR(J),J=1,NRW)
      WRITE (6,951)
      DO 404 I=1,NTYPE
      WRITE (6,452) I,(PRWYT(I,J),J=1,NRW)
404   CONTINUE
      STOP
      END
```

E.2 Listing of the DELCAP Simulation

```
+N GEN   4        N RWAY  31 2 I   1O      F               Q    2 F          PTYPEI
+N NXTOP4         N OP    32 2 I   2RW     F                                 PRWAYI
+N LAND  4                         3TYP    F
+N TOFF  4                         4DX     F                                 FREERF
+N CDIR  4        N PT     4   I   5H      F
+N FTIUP4         T TYPE   1   I   6OPER   1    T
+N PRINT4         N DLAY   4   F   7DOM    1    F
+T FLT   4        T TIN    3   F   8NPT    1    T
+T TIEUP4                          9FLYOM  2    F
+N FNDS  2        T TMIN   1   F  10SQRW   2    T
+N CHOUR2         T TMAX   2   F  11VLAND  1    F
+                                 12VTOFF  1    F
+                                 13ROTL   1    F
+                                 14ROTT   1    F
+                 T SQ     4   I  15VTAXI  0    F
+                                 16DAFIX  0    F
+                                 17SEPLL  2    F
+                                 18SEPTL  0    F
+                                 19CALIN  1    F
+                                 20CTYPE  2    F
+                                 21CRWYT  2    F
+                                 22CRWYL  2    F
+                                 23SQOP   2    T
+                                 24NEXT   1    T
+                                 25LAST   1    T
+                                 26DINT   2    F
+                                 27FQ     2    T
+                                 28LQ     2    T
+                                 29RET    2    T
+                                 30TPT    2    T
+                                 31TPMIN  1    F
+                                 32SEPTT  2    F
+                                 33NAPP   1    T
+                                 34NDEP   1    T
+                                 35NLAND  1    T
+                                 36NTOFF  1    T
+                                 37DELT   1    F
+                                 38DELL   1    F
+                                 39TBEG   0    F
+                 T POMTI  3   I  40FOMTI  1    T          OMTI1   RTMAX   L
+                 T SOMTI  4   I  41LOMTI  1    T          THTI1   RTMAX   L
+                 T PTHTI  3   I  42FTHTI  1    T          ERTI1   RTMAX   L
+                 T STHTI  4   I  43LTHTI  1    T
+                 T PERTI  3   I  44FERTI  1    T
+                 T SERTI  4   I  45LERTI  1    T
+                                 46TEND   0    F
+                                 47LAMBD  2    F
+                                 48IHOUR  0    T
+                                 49SEP2   2    F
+                                 50GENN   1    T
+                                 51TDRW   2    F
+                                 52HDRW   2    F
```

```
+                              53TMRW   2    I
+                              54HMRW   2    I
+                              55TMITR  0    I
+                              56CAP    0    I
+                              57INDY   1    I
+                              58TINDY  1    I
+                              59CHGD   1    I
+                              60AFIN   1    F
+                              61CF     2    I
+                              62SLOT   F
+                              63NPLAY  2    I
+                              64INC    0    F
+                              65IDT    1    I
+                              66DTIM   0    F
+                              67TIM    2    F
```

```
EVENTS
 3 EXOGENOUS
   BEGIN (1)
   EXGEN (2)
   CHGOP(3)
 9 ENDOGENOUS
   GEN
   NXTOP
   LAND
   TOFF
   FTIMP
   CHOIP
   PRINT
   ENDS
    COIP
END  EVENT LIST
```

```
      EXOGENOUS EVENT BEGIN
      DO TO 1, FOR EACH O I
      CREATE GEN
      STORE I IN OP(GEN)
      STORE GEN IN GENN(I)
      CALL RND(**INITR,*R)
      LET T=TIME-LAMBD(I,THOUR)*ALOG(1.-R)
      CAUSE GEN AT T
1     LOOP
      CREATE ENDS
      CAUSE ENDS AT TEND
      CREATE CHOUR
      CAUSE CHOUR AT TIME+1.
      IF CAP GT 0, GO TO 2
      WRITE ON TAPE 6
      FORMAT ('1',S20,'HOURLY THROUGHPUT'
     1/' HOUR  RUNWAY',S5,'LANDINGS TAKEOFFS  TOTAL'/)
      RETURN
2     WRITE ON TAPE 6
      FORMAT ('1',S20,'HOURLY THROUGHPUT',S9,'HOURLY DELAY PER AIRCRAFT'
     1/' HOUR  RUNWAY',S5,'LANDINGS TAKEOFFS  TOTAL',S5,
     2'LANDINGS TAKEOFFS     ALL'/)
      RETURN
      END BEGIN
```

```
      ENDOGENOUS EVENT GEN
C     GEN  GENERATES LANDINGS AND TAKEOFFS AND
C     ASSIGNS ATTRIBUTES TO THEM.
C     OP(GEN) IS 1- TAKEOFF , OR 2-LANDING
      STORE OP(GEN) IN I
C     GEN SCHEDULES ITSELF TO OCCUR AGAIN AFTER A TIME INTERVAL
C     DEPENDING ON THE RATE OF OPERATION.
      CALL RND(**INITR,*R)
      CAUSE GEN AT TIME-LAMBD(I,THOUR)*ALOG(1.-R)
      CREATE FLT
      LET IT=PTYPE(I)
      STORE IT IN TYPE(FLT)
      LET K=PRWAY(I,IT)
      GO TO (1,2),I
C     TIN(FLT)  IS THE TIME A FLIGHT IS AVAILABLE TO BEGIN FINAL
C     DESCENT (FOR LANDINGS) OR TO BEGIN TAXIING TO RUNWAY(FOR TAKEOFF)
C     CALIN IS A TIME LAG INTRODUCED IN TAKEOFFS, CORRESPONDING TO
C     FLYOM - THE TIME A LANDING TAKES TO FLY FROM
C     HANDOFF TO THE OUTER MARKER.
 1    LET TIN(FLT)=TIME+CALIN(K)
      GO TO 3
 2     LET TIN(FLT)=TIME+FLYOM(IT,K)
 3     IF Q(K,I) IS NOT EMPTY, GO TO 4
      CREATE NXTOP
      LET RWAY(NXTOP)=K
      CAUSE NXTOP AT TIN(FLT)
C     Q(K,I) - IS THE QUEUE OF PLANES WAITING TO TAKEOFF(I=1),
C     OR LAND(I=2) ON RUNWAY K.
 4    FILE FLT IN Q(K,I)
      RETURN
      END GEN




      EXOGENOUS EVENT EXGEN
C     EXGEN GENERATES EXPLICIT DEPARTURES AND ARRIVALS
      SAVE EVENT CARD
      CREATE FLT
      READ I,K,IT
      FORMAT (3I2)
      STORE IT IN TYPE(FLT)
      GO TO (1,2),I
 1    LET TIN(FLT)=TIME+CALIN(K)
      GO TO 3
 2    LET TIN(FLT)=TIME+FLYOM(IT,K)
 3    IF  Q(K,I) IS NOT EMPTY, GO TO 4
      CREATE NXTOP
      LET RWAY(NXTOP)=K
      CAUSE NXTOP AT TIN(FLT)
 4    FILE FLT IN Q(K,I)
      RETURN
      END
```

```
      FUNCTION PTYPE(I)
C     PTYPE CHOOSES AN AIRCRAFT TYPE FOR EACH FLIGHT ACCORDING  TO
C     CTYPE - THE CUMULATIVE DISTRIBUTION OF A/C TYPES IN THE MIX.
      CALL RND(**INITR,*R)
      DO TO 1, FOR EACH TYP J
      IF R LE CTYPE(I,J), GO TO 2
1      LOOP
2     LET PTYPE=J
      RETURN
      END PTYPE


      FUNCTION PRWAY(I,M)
C     PRWAY CHOOSES A RUNWAY FOR EACH FLIGHT ACCORDING TO
C     CRWYL - THE CUMULATIVE DISTRIBUTION OF PRWYL(SEE PREPROCESSOR),OR
C     CRWYT - SAME AS CRWYL FOR TAKEOFFS.
      CALL RND(**INITR,*R)
      DO TO 3, FOR EACH RW J
      GO TO (1,2),I
1     IF R LE CRWYT(M,J), GO TO 4
      GO TO 3
2     IF R LE CRWYL(M,J), GO TO 4
3     LOOP
4     LET PRWAY=J
      RETURN
      END PRWAY
```

```
      ENDOGENOUS EVENT NXTOP
      DIMENSION  IRW(20)
C     NXTOP DECIDES WHICH OPERATION WILL BE SCHEDULED NEXT
C     ON EACH RUNWAY.
      STORE RWAY(NXTOP) IN K
      DESTROY NXTOP
      LET KRW=INDX(K)
      IF KRW EQ 0, RETURN
      IF NEXT(KRW) NE 0, RETURN
      IF LAST(KRW) GT NSOOP(KRW), LET LAST(KRW)=1
      IF OPER(KRW) EQ 4, LET LAST(KRW)=1
      LET II=LAST(KRW)
      LET IEND=II
      LET TMN=999999
      LET IMIN=0
1     LET K=SORW(KRW,II)
      LET I=SOOP(KRW,II)
      FIND FIRST,FOR EACH FLT IN Q(K,I),IF NONE, GO TO 2
      STORE FLT IN F
      LET T=FREER(K,I,F)
      IF TIM(F) LE T, GO TO 3
      IF T GT TMN, GO TO 2
      LET TMN=T
      LET IMIN=II
      STORE F IN MNF
2     LET II=II+1
      IF II GT NSOOP(KRW),LET II=1
      IF II NE IEND, GO TO 1
      GO TO 4
3     LET IMIN=II
      LET TMN=T
      STORE F IN MNF
4     IF IMIN EQ 0, RETURN
      LET I=SOOP(KRW,IMIN)
      LET K=SORW(KRW,IMIN)
      GO TO (5,6),I
5     CREATE TOFF
      STORE K IN RWAY(TOFF)
      CAUSE TOFF AT TMN
      GO TO 7
6      CREATE LAND
      STORE K IN RWAY(LAND)
      CAUSE LAND AT TMN
7     LET LAST(KRW)=IMIN
      LET NEXT(KRW)=IMIN
      IF INDX(K) EQ 0, RETURN
      LET KRW=INDX(K)
      IF ONE NE QF(K,I), RETURN
      LET QF(K,I)=0
      LET NIN=NSOOP(KRW)
      LET MXW=0
```

```
      DO TO 10, FOR J=(1)(NIN)
      LET I=SOOP(KRW,J)
      LET K=SORW(KRW,J)
      IF QF(K,I) NE 0, RETURN
      IF MRW EQ 0, GO TO 9
      DO TO 8, FOR MM=(1)(MRW)
      IF K EQ IRW(MM), GO TO 10
8     LOOP
9     LET MRW=MRW+1
      LET IRW(MRW)=K
10    LOOP
      LET T=TMN+.0001
      DO TO 11, FOR I=(1)(MRW)
      CREATE CDIR
      STORE IRW(I) IN RWAY(CDIR)
      CAUSE CDIR AT T
11    LOOP
      RETURN
      END NXTOP
```

```
      FUNCTION FREER(K,I,FLT)
C     FREER CALCULATES THE FIRST TIME AT WHICH FLIGHT FLT CAN PERFORM
C     OPERATION I ON RUNWAY K WITHOUT VIOLATING SEPARATION RULES.
      DIMENSION TR(25)
      LET J=0
       LET T=TIME
      IF TIN(FLT) GT T, LET T=TIN(FLT)
      LET M=TYPE(FLT)
      LET FREER=T
      IF I EQ 2, GO TO 4
      IF ERTI(K) IS EMPTY, RETURN
C     ERTI(K) IS THE SET OF 'TIEUPS' FOR THE END OF THE RUNWAY K.
C     A TIEUP IS A TIME INTERVAL DURING WHICH NO TAKEOFF MAY OCCUPY
C     THE END OF THE RUNWAY DUE TO INTERFERENCE FROM OTHER AIRCRAFT.
      LET TEM=TDMIN(K)
C     TDMIN IS A TIME LAG INTRODUCED INTO THE SCHEDULE OF A TAKEOFF
C     CORRESPONDING TO THE TIME IT TAKES A LANDING TO FLY FROM THE
C     OUTER MARKER TO TOUCHDOWN.  IT MAY BE LOOSELY THOUGHT OF AS
C     TAXIING TIME.
      DO TO 3,FOR EACH TIEUP IN ERTI(K)
      LET TT=TMAX(TIEUP)-TEM
C     THE END OF THE TIEUP, I.E. THE TIME WHEN THE END OF THE RUNWAY
C     BECOMES FREE, IS DISPLACED BACKWARDS TO GIVE THE TIME WHEN
C     THE TAKEOFF MAY BEGIN TAXI.
      IF TT LS T , GO TO 3
      LET J=J+1
      LET TR(J)=TT
 3    LOOP
      GO TO 12
    4 IF OMTI(K) IS EMPTY, GO TO 8
C     OMTI IS THE SET OF TIEUPS FOR THE OUTER MARKER.
      DO TO 5, FOR EACH TIEUP IN OMTI(K)
      LET TT=TMAX(TIEUP)
      IF TT LS T , GO TO 5
      LET J=J+1
      LET TR(J)=TT
 5    LOOP
    8 IF THTI(K) IS EMPTY, GO TO 12
      LET TEM=DOM(K)/VLAND(M)
C     THTI IS THE SET OF TIEUPS FOR THE THRESHOLD OF THE RUNWAY.
      DO TO 9, FOR EACH TIEUP IN THTI(K)
C     THRESHOLD TIEUPS ARE DISPLACED BACKWARDS TO GIVE THE TIME THAT
C     THE LANDING MAY PASS THE OUTER MARKER.
      LET TT=TMAX(TIEUP)-TEM
      IF TT LS T , GO TO 9
      LET J=J+1
      LET TR(J)=TT
 9    LOOP
 12   IF J EQ 0, RETURN
      LET FREER=TR(1)
      IF J EQ 1, RETURN
C     FREER IS SET EQUAL TO THE END OF THE LATEST TIEUP, WHEN THERE IS
C     NO LONGER ANY INTERFERENCE.
      DO TO 21, FOR JJ=(1)(J)
      IF TR(JJ) GT FREER, LET FREER=TR(JJ)
 21   LOOP
      RETURN
      END FREER
```

```
      ENDOGENOUS EVENT LAND
C     LAND CREATES ALL THE 'TIEUPS' WHICH
C     RESULT FROM AN AIRCRAFT LANDING.
      STORE RWAY(LAND) IN K
      IF Q(K,2) IS NOT EMPTY, GO TO 9
      WRITE ON TAPE 6, TIME,K
      FORMAT (' AT TIME',M3.2.2,S2,'LANDING QUEUE FOR RUNWAY',I3,S2,
     1   'IS EMPTY')
      STOP
 9
C     FIND THE LANDING TO BE 'SCHEDULED' AND STORE ITS ATTRIBUTES.
      REMOVE FIRST FLT FROM Q(K,2)
      STORE FLT IN FL
      LET M=TYPE(FL)
      LET V=VLAND(M)
      LET T = FREER(K,2,FL)
      LET TD=T+DOM(K)/V
C     TIE UP THRESHOLD TO LANDING AIRCRAFT FROM TOUCHDOWN TIME UNTIL
C     AFTER RUNWAY OCCUPANCY TIME HAS ELAPSED.
      CREATE TIEUP
      LET TMIN(TIEUP)=TD
      LET TMAX(TIEUP)=TD+ROTL(M)
      FILE TIEUP IN THTI(K)
      CREATE FTIUP
      STORE K   IN RWAY(FTIUP)
      STORE 2 IN PT(FTIUP)
      CAUSE FTIUP AT TMAX(TIEUP)
C     TIE UP END OF RUNWAY TO DEPARTING AIRCRAFT FROM TOUCHDOWN UNTIL
C     AFTER RUNWAY OCCUPANCY TIME HAS ELAPSED.
      CREATE TIEUP
      LET TMIN(TIEUP)=TD
      LET TMAX(TIEUP)=TD+ROTL(M)
      FILE TIEUP IN ERTI(K)
      CREATE FTIUP
      STORE K   IN RWAY(FTIUP)
      STORE 3 IN PT(FTIUP)
      CAUSE FTIUP AT TMAX(TIEUP)
C     FIND THE FOLLOWING PLANE IN THE LANDING QUEUE
C     AND STORE ITS ATTRIBUTES.
      FIND FIRST, FOR EACH FLT IN Q(K,2),IF NONE, GO TO 11
      STORE FLT IN F
      LET MM=TYPE(F)
      LET S=VLAND(MM)
C     CREATE A TIEUP WHICH WILL MAINTAIN PROPER RADAR SEPARATION
C     BETWEEN ARRIVING AIRCRAFT.
      CREATE TIEUP
      IF S GE V, GO TO 20
C     IF THE LANDING SPEED OF THE PLANE BEING 'SCHEDULED' IS GREATER
C     THAN THAT OF THE FOLLOWING PLANE, TIE UP THE OUTER MARKER FROM
C     THE TIME THE FIRST PLANE PASSES THE OUTER MARKER UNTIL
C     THE TIME IT TAKES THE SECOND TO FLY THE SEPARATION DISTANCE
C     HAS ELAPSED.
      LET TMIN(TIEUP)=T
      LET TMAX(TIEUP)=T+SEPLL(M,MM)/S
      FILE TIEUP IN OMTI(K)
      CREATE FTIUP
      STORE K   IN RWAY(FTIUP)
```

```
      STORE 1  IN PT(FTIUP)
      CAUSE FTIUP AT TMAX(TIEUP)
      GO TO 11
C     IF THE LANDING SPEED OF THE FOLLOWING PLANE IS GREATER, TIE UP
C     THE THRESHOLD FROM TOUCHDOWN OF THE FIRST UNTIL THE TIME IT TAKES
C     THE SECOND TO FLY THE SEPARATION DISTANCE HAS ELAPSED.
   20 LET TMIN(TIEUP) = TD
      LET TMAX(TIEUP)=TD+SEPLL(M,MM)/S
      FILE TIEUP IN THTI(K)
      CREATE FTIUP
      STORE K  IN RWAY(FTIUP)
      STORE 2 IN PT(FTIUP)
      CAUSE FTIUP AT TMAX(TIEUP)
C     CREATE A TIEUP WHICH WILL MAINTAIN PROPER SEPARATION BETWEEN
C     THIS LANDING AND A TAKEOFF ON THE SAME RUNWAY.
11    FIND FIRST, FOR EACH FLT IN Q(K,1), IF NONE, GO TO 2
      CREATE TIEUP
      LET TMAX(TIEUP)=TD
      STORE FLT IN F
      LET MM=TYPE(F)
      LET S=VTOFF(MM)
      LET TMIN(TIEUP)=T+(DOM(K)-(SEPTL+.5*V**2/S*ROTT(MM)))/V
  101 FILE TIEUP IN FRTI(K)
      CREATE FTIUP
      STORE K  IN RWAY(FTIUP)
      STORE 3 IN PT(FTIUP)
      CAUSE FTIUP AT TMAX(TIEUP)
 2    IF NPT(K)  EQ 0, GO TO 10
C     NOW CREATE TIEUPS ON OTHER RUNWAYS, IF SUCH INTERFERENCE EXISTS.
      DO TO 3,FOR J=(1)(NPT(K))
      CREATE TIEUP
C     KK IS THE RUNWAY AFFECTED.
      LET KK=RPT(K,J)
C     IT IS THE TYPE OF TIEUP TO BE CREATED.
C     TIEUP TYPES 1, 2, AND 6 APPLY TO LANDINGS.
      LET IT=TPT(K,J)
      GO TO (3,4,6,6,6,5),IT
C     CREATE A TIEUP TO MAINTAIN INTER-ARRIVAL SEPARATION.
    3 FIND FIRST, FOR EACH FLT IN Q(KK,2), IF NONE, GO TO 6
      STORE FLT IN F
      LET MM=TYPE(F)
      LET S=VLAND(MM)
      IF S GE V, GO TO 325
      LET TMIN(TIEUP)=T
      LET TMAX(TIEUP)=T+SEPLL(M,MM)/S
      LET JJ=1
      GO TO 7
  325 LET TMIN(TIEUP)=TD
      LET TMAX(TIEUP)=TD+SEPLL(M,MM)/S
      LET JJ=2
      GO TO 7
C     CREATE A TIEUP TO MAINTAIN DEP/ARR SEPARATION.
    4 LET TMAX(TIEUP)=TD
  425 FIND FIRST , FOR EACH FLT IN Q(KK,1), IF NONE GO TO 6
      STORE FLT IN F
      LET MM=TYPE(F)
      LET S=VTOFF(MM)
      LET TMIN(TIEUP)=T+(DOM(K)-(SEPTL+.5*V**2/S*ROTT(MM)))/V
```

```
 450 LET JJ=3
     GO TO 7
C    TIE UP THE END OF AN INTERSECTING RUNWAY TO TAKEOFFS AND LANDINGS
C    UNTIL AFTER THE LANDING  PASSES THE INTERSECTION.
   5 LET TMIN (TIEUP) =TD
     LET A=(VTAXI-V)/ROTL(M)
     LET TEM=.5*A*ROTL(M)**2+V*ROTL(M)
C    IF THE LANDING WILL NOT REACH THE INTERSECTION,
C    TIE UP UNTIL THE LANDING TURNS OFF.
     IF TEM LE DINT(K,KK), GO TO 51
     LET B=V**2+2.*A*DINT(K,KK)
     LET TUP=TD+(-V+SQRT(B))/A
     GO TO 52
 51  LET TUP=TD+ROTL(M)
 52  LET TMAX(TIEUP)=TUP
     FILE TIEUP IN THTI(KK)
     CREATE FTIUP
     STORE KK IN RWAY(FTIUP)
     STORE 2 IN PT(FTIUP)
     CAUSE FTIUP AT TMAX(TIEUP)
     CREATE TIEUP
     LET TMIN(TIEUP)=TD
     LET TMAX(TIEUP)=TUP
     LET JJ=3
     GO TO 7
   6 DESTROY TIEUP
     GO TO 8
   7 GO TO(701,702,703),JJ
 701 FILE TIEUP IN OMTI(KK)
     GO TO 705
 702 FILE TIEUP IN THTI(KK)
     GO TO 705
 703 FILE TIEUP IN ERTI(KK)
 705 CREATE FTIUP
     STORE KK IN RWAY(FTIUP)
     STORE JJ IN PT(FTIUP)
     CAUSE FTIUP AT TMAX(TIEUP)
 8   LOOP
 10  CREATE NXTOP
     STORE K IN RWAY(NXTOP)
     LET KK=INDX(K)
     LET NEXT(KK)=0
     CAUSE NXTOP AT T
C    DTEM IS THE DELAY ENCOUNTERED BY THIS LANDING.
     LET DTEM=(T-TIN(FL))*60.
     IF TD LS TBEG,GO TO 50
     CREATE PRINT
C    STORE DATA TO BE RECORDED AT TOUCHDOWN.
     STORE DTEM IN DLAY(PRINT)
     STORE K IN RWAY(PRINT)
     STORE 2 IN OP(PRINT)
     CAUSE PRINT AT TD
 50  DESTROY FLT CALLED FL
     LET LAST(KK)=LAST(KK)+1
     DESTROY LAND
     RETURN
     END LAND
```

```
      ENDOGENOUS EVENT TOFF
C     TOFF CREATES THE TIEUPS RESULTING FROM AN AIRCRAFT TAKING OFF.
      STORE RWAY(TOFF) IN K
      DESTROY TOFF
      IF Q(K,1) IS EMPTY, GO TO 16
C     FIND TAKEOFF TO BE SCHEDULED AND STORE ITS ATTRIBUTES.
      REMOVE FIRST FLT FROM Q(K,1)
      STORE FLT IN FL
      LET M=TYPE(FL)
      LET V=VTOFF(M)
      LET T=FPFER(K,1,FL)
      LET TD=T+TDMIN(K)
C     TIE UP THE RUNWAY TO TAKEOFFS AND LANDINGS FOR DURATION OF THE
C     RUNWAY OCCUPANCY TIME.
      CREATE TIEUP
      LET TMIN(TIEUP)=TD
      LET TMAX(TIEUP)=TD+ROTT(M)
      FILE TIEUP IN THTI(K)
      CREATE FTIUP
      STORE K  IN RWAY(FTIUP)
      STORE 2 IN PT(FTIUP)
      CAUSE FTIUP AT TMAX(TIEUP)
      CREATE TIEUP
      LET TMIN(TIEUP)=TD
      LET TMAX(TIEUP)=TD+ROTT(M)
      FILE TIEUP IN ERTI(K)
      CREATE FTIUP
      STORE K  IN RWAY(FTIUP)
      STORE 3 IN PT(FTIUP)
      CAUSE FTIUP AT TMAX(TIEUP)
      FIND FIRST, FOR EACH FLT IN Q(K,1), IF NONE, GO TO 2
      STORE FLT IN F
      LET MM=TYPE(F)
C     TIE UP THE END OF THE RUNWAY TO THE NEXT TAKEOFF LONG ENOUGH
C     TO MAINTAIN INTER-DEPARTURE SEPARATION. THIS DEPENDS ON THE
C     TYPES OF THE TWO AIRCRAFT.
      CREATE TIEUP
      LET TMIN(TIEUP)=TD
      LET TMAX(TIEUP)=TD+SEPTT(M,MM)
      FILE TIEUP IN ERTI(K)
      CREATE FTIUP
      STORE K  IN RWAY(FTIUP)
      STORE 3 IN PT(FTIUP)
      CAUSE FTIUP AT TMAX(TIEUP)
2     FIND FIRST, FOR EACH FLT IN Q(K,2), IF NONE, GO TO 5
      STORE FLT IN F
      LET S=VLAND(TYPE(F))
C     CREATE A TIEUP TO MAINTAIN DEP/ARR SEPARATION.
      CREATE TIEUP
      LET TMIN(TIEUP)=TD
      LET TMAX(TIEUP)=TD+(SEPTL+.5*S**2/V*ROTT(M))/S
    4 FILE TIEUP IN THTI(K)
      CREATE FTIUP
      STORE K IN RWAY(FTIUP)
      STORE 2 IN PT(FTIUP)
      CAUSE FTIUP AT TMAX(TIEUP)
5     IF NPT(K) EQ 0, GO TO 15
```

```
C       CREATE TIEUPS OF OTHER RUNWAYS AS REQUIRED.
        DO TO 14,FOR J=(1)(NPT(K))
        CREATE TIEUP
C       KK - RUNWAY AFFECTED
        LET KK=RPT(K,J)
C       IT - TYPE OF TIEUP
C       ONLY TYPES 3, 4, 5, AND 6 APPLY TO TAKEOFFS.
        LET IT=TPT(K,J)
        GO TO(12,12,6,8,8,10),IT
C       CREATE A TIEUP TO MAINTAIN PROPER DEP/APR SEPARATION.
      6 FIND FIRST,FOR EACH FLT IN Q(KK,2), IF NONE,GO TO 12
        STORE FLT IN F
        LET MM=TYPE(F)
        LET S=VLAND(MM)
        LET TMIN(TIEUP)=TD
        LET JJ=2
        LET TMAX(TIEUP)=TD+(SEPTL+.5*S**2/V*ROTT(M))/S
        GO TO 13
      8 FIND FIRST,FOR EACH FLT IN Q(KK,1), IF NONE, GO TO 12
        STORE FLT IN F
        LET MM=TYPE(F)
C       CREATE A TIEUP TO MAINTAIN PROPER INTER-DEPARTURE SEPARATION.
        LET TMIN(TIEUP)=TD
C       IF THE RUNWAYS ARE DEPENDENT, USE THE SAME SEPARATION AS FOR ONE
C       RUNWAY, I.E. THOSE IN THE SEPTT ARRAY.
        LET TMAX(TIEUP)=TD+SEPTT(M,MM)
C       IF THE RUNWAYS ALLOW SIMULTANEOUS DEPARTURES WHEN THEY DIVERGE,
C       USE THE SEPARATIONS IN THE SEP2 ARRAY.
        IF IT EQ 5,LET TMAX(TIEUP)=TD+SEP2(M,MM)
        LET JJ=3
        GO TO 13
C       TIE UP THE END OF AN INTERSECTING RUNWAY TO ALL OPERATIONS UNTIL
C       THE TAKEOFF PASSES THE INTERSECTION.
 10     LET TMIN(TIEUP)=TD
        LET A =V/ROTT(M)
        LET TEM=.5*A*ROTT(M)**2+V*ROTT(M)
C       IF THE TAKEOFF IS AIRBORNE BEFORE REACHING THE INTERSECTION,
C       TIE UP ONLY UNTIL AIRBORNE.
        IF TEM LE DINT(K,KK), GO TO 51
        LET B=V**2+2.*A*DINT(K,KK)
        LET TUP=TD+(-V+SQRT(B))/A
        GO TO 52
 51     LET TUP=TD+ROTT(M)
 52     LET TMAX(TIEUP)=TUP
        FILE TIEUP IN THTI(KK)
        CREATE FTIUP
        STORE KK IN RWAY(FTIUP)
        STORE 2 IN PT(FTIUP)
        CAUSE FTIUP AT TMAX(TIEUP)
        CREATE TIEUP
        LET TMIN(TIEUP) =TD
        LET TMAX(TIEUP)=TUP
        LET JJ=3
        GO TO 13
     12 DESTROY TIEUP
        GO TO 14
     13 GO TO(14,131,132),JJ
    131 FILE TIEUP IN THTI(KK)
```

```
      GO TO 135
  132 FILE TIFUP IN FRTI(KK)
  135 CREATE FTIUP
      STORE KK IN RWAY(FTIUP)
      STORE JJ IN PT(FTIUP)
      CAUSE FTIUP AT TMAX(TIFUP)
   14 LOOP
 15     CREATE NXTOP
      STORE K IN RWAY(NXTOP)
      LET KK=INDX(K)
      LET NEXT(KK)=0
      CAUSE NXTOP AT T
C     DTEM - THE DELAY INCURRED BY THIS TAKEOFF
      LET DTEM=(TD-TDMIN(K)-TIN(FL))*60.
      IF TD LS TBEG,GO TO 50
      CREATE PRINT
C     STORE DATA TO BE RECORDED AT THE TIME THE TAKFOFF TURNS
C     ON TO THE RUNWAY.
      STORE DTEM IN DLAY(PRINT)
      STORE K IN RWAY(PRINT)
      STORE 1 IN OP(PRINT)
      CAUSE PRINT AT TD
 50   DESTROY FLT CALLED FL
      LET LAST(KK)=LAST(KK)+1
      RETURN
 16     WRITE ON TAPE 6, TIME, K
      FORMAT (' AT TIME',D2.4,S2,'TAKEOFF QUEUE FOR RUNWAY',I3,S2,
     1  'IS EMPTY')
      STOP
      END TOFF
```

```
      ENDOGENOUS EVENT FTIUP
C     FTIUP REMOVES TIEUPS FROM THEIR SETS AND DESTROYS THEM WHEN
C     SIMULATED TIME PASSES THE END-LIMIT OF THE TIEUP.
      STORE RWAY(FTIUP) IN K
      STORE PT(FTIUP) IN J
      DESTROY FTIUP
      GO TO(10,20,30),J
   10 REMOVE FIRST TIEUP FROM OMTI(K)
      GO TO 40
   20 REMOVE FIRST TIEUP FROM THTI(K)
      GO TO 40
   30 REMOVE FIRST TIEUP FROM ERTI(K)
   40 DESTROY TIEUP
      RETURN
      END FTIUP
```

```
      ENDOGENOUS EVENT PRINT
C     PRINT  RECORDS DATA ON EACH FLIGHT AT THE TIME IT ACTUALLY
C     TOUCHES DOWN OR TURNS ON TO THE RUNWAY, AS THE CASE MAY BE.
      STORE RWAY(PRINT) IN K
      STORE DLAY(PRINT) IN D
      STORE OP(PRINT) IN I
      DESTROY PRINT
      LET HDRW(K,I)=HDRW(K,I)+D
      LET HNRW(K,I)=HNRW(K,I)+1
C     NTOFF AND NLAND ARE THE TOTAL NUMBER OF TAKFOFFS AND LANDINGS
C     DURING THIS HOUR.
C     DELT AND DELL ACCUMULATE TOTAL DELAY ON TAKFOFFS AND
C     LANDINGS BY HOUR.
      LET ID=D/INC+1.
      IF ID GT NSLOT, LET ID=NSLOT
      IF ID LE 0, LET ID=1
      LET NDLAY(IHOUR,ID)=NDLAY(IHOUR,ID)+1
      GO TO(10,20),I
   10 LET NTOFF(IHOUR)=NTOFF(IHOUR)+1
      LET DELT(IHOUR)=DELT(IHOUR)+D
      RETURN
   20 LET NLAND(IHOUR)=NLAND(IHOUR)+1
      LET DELL(IHOUR)=DELL(IHOUR)+D
      RETURN
      END PRINT
```

```
        ENDOGENOUS EVENT CHOUR
        LET IHOUR=IHOUR+1
        IF IHOUR GT NH, LET IHOUR=1
        LET T=TIME+1.
        IF T LE TEND, CAUSE CHOUR AT T
        DO TO 1, FOR EACH O I
        STORE GENN(I) IN GEN
        CANCEL GEN
        CALL RND(**INITR,*R)
        CAUSE GEN AT TIME-LAMBD(I,IHOUR)*ALOG(1.-R)
1       LOOP
        IF TIME LE TBEG, RETURN
        LET II=IHOUR-1
        DO TO 4, FOR EACH RW K
        LET NOPS=HNRW(K,1)+HNRW(K,2)
        DO TO 12, FOR EACH O I
        LET TNRW(K,I)=TNRW(K,I)+HNRW(K,I)
12       LOOP
        IF CAP GT 0, GO TO 11
        IF K GT 1, GO TO 20
        WRITE ON TAPE 6, II,K,HNRW(K,2),HNRW(K,1),NOPS
        FORMAT (I4,I6,S4,3I9)
        GO TO 22
20      WRITE ON TAPE 6,     K,HNRW(K,2),HNRW(K,1),NOPS
        FORMAT (S4,I6,S4,3I9)
        GO TO 22
11      LET TDEL=0.
        DO TO 2, FOR EACH O I
        LET TDRW(K,I)=TDRW(K,I)+HDRW(K,I)
        LET TDEL=TDEL+HDRW(K,I)
2       LOOP
        LET B1=HNRW(K,1)
        IF B1 GT 0., GO TO 5
        LET D1=0.
        GO TO 6
5       LET D1=HDRW(K,1)/B1
6       LET B2=HNRW(K,2)
        IF B2 GT 0.,GO TO 7
        LET D2=0.
        GO TO 8
7       LET D2=HDRW(K,2)/B2
8       LET B3=NOPS
        IF B3 GT 0., GO TO 9
        LET D3=0.
        GO TO 10
9       LET D3=TDEL/B3
10      IF K GT 1, GO TO 21
        WRITE ON TAPE 6, II,K,HNRW(K,2),HNRW(K,1),NOPS,D2,D1,D3
        FORMAT (I4,I6,S4,3I9,S3,3D7.1)
        GO TO 22
21      WRITE ON TAPE 6,     K,HNRW(K,2),HNRW(K,1),NOPS,D2,D1,D3
        FORMAT (S4,I6,S4,3I9,S3,3D7.1)
22      DO TO 3, FOR EACH O I
        LET HDRW(K,I)=0.
        LET HNRW(K,I)=0
3       LOOP
4       LOOP
        RETURN
        END CHOUR
```

```
      EXOGENOUS EVENT CHGOP
C THIS EVENT READS THE NEW OPERATING POLICY AND RUNWAY PREFERENCES AND
C INITIATES THE CHANGEOVER.
      DO TO 1, FOR EACH RW K
      READ INDX(K),CHGD(K)
      FORMAT (S2,2I2)
 1    LOOP
      DO TO 3, FOR EACH RW K
      DO TO 2, FOR EACH TYP J
      READ CRWYT(J,K),CRWYL(J,K)
      FORMAT (S4,2D2.4)
 2    LOOP
 3    LOOP
      IF TIME LT TBEG, GO TO 54
      LET T=TIME-DTIM
      DO TO 53, FOR EACH RW K
      LET KRW=INDX(K)
      IF KRW LE 0, GO TO 53
      LET NIN=NSOOP(KRW)
      LET I1=0
      LET I2=0
      DO TO 51, FOR J=(1)(NIN)
      LET KK=SORW(KRW,J)
      IF KK NE K, GO TO 51
      LET II=SOOP(KRW,J)
      IF II EQ 1, LET I1=1
      IF II EQ 2, LET I2=2
51    LOOP
      IF I1 EQ 0, GO TO 52
      LET TIM(K,1)=TIM(K,1)+T
52    IF I2 EQ 0, GO TO 53
      LET TIM(K,2)=TIM(K,2)+T
53    LOOP
      LET DTIM=TIME
 54   DO TO 63, FOR EACH RW K
      LET QF(K,1)=0
      LET QF(K,2)=0
      LET II=INDX(K)
      IF II EQ 0, GO TO 63
      LET NN=NSOOP(II)
      DO TO 62, FOR J=(1)(NN)
      LET KK=SORW(II,J)
      IF KK NE K, GO TO 62
      LET I=SOOP(II,J)
      IF Q(K,I) IS EMPTY, GO TO 62
      LET QF(K,I)=LQ(K,I)
 62    LOOP
 63   LOOP
```

```
      DO TO 100, FOR EACH RW K
 70   LET KRW=TNDX(K)
      IF KRW EQ 0, GO TO 100
      IF OPER(KRW) LE 5, GO TO 73
      LET NIN=NSOOP(KRW)
      DO TO 72, FOR I=(1)(NIN)
      LET KK=SQRW(KRW,I)
      DO TO 71, FOR EACH Q II
      IF OF(KK,II) NE 0, GO TO 100
 71   LOOP
 72   LOOP
 73   IF CHGD(K) GT 0, GO TO 80
 74   LET INDX(K)=TNDX(K)
      LET TNDX(K)=0
      GO TO 100
 80   CREATE CDIR
      STORE K IN RWAY(CDIR)
      CAUSE CDIR AT TIME
100   LOOP
      RETURN
      END CHOOP
```

```
      ENDOGENOUS EVENT CDIR
      DIMENSION  IRW(20)
      STORE RWAY(CDIR) IN K
      IF CHGD(K) EQ 0, GO TO 1
      CAUSE CDIR AT TIME+AFIN(K)
      LET CHGD(K)=0
      RETURN
1     DESTROY CDIR
      LET KRW=TNDX(K)
      IF KRW EQ 0, RETURN
      LET MRW=1
      LET IRW(1)=K
      IF OPER(KRW) LE 4, GO TO 6
      LET NN=NSOOP(KRW)
      DO TO 4, FOR I=(1)(NN)
      LET KK=SQRW(KRW,I)
      IF MRW EQ 0, GO TO 3
      DO TO 2, FOR J=(1)(MRW)
      IF KK EQ IRW(J), GO TO 4
2     LOOP
3     LET MRW=MRW+1
      LET IRW(MRW)=KK
4     LOOP
6     DO TO 5, FOR KK=(1)(MRW)
      LET K=IRW(KK)
      LET INDX(K)=TNDX(K)
      LET TNDX(K)=0
5     LOOP
      RETURN
      END CDIR
```

```
      ENDOGENOUS EVENT ENDS
      WRITE ON TAPE 6, INITR
      FORMAT ('0'//'0FINAL RANDOM NUMBER SEED ',O12)
      LET T=TIME-DTIM
      DO TO 53, FOR EACH RW K
      LET KRW=INDX(K)
      IF KRW LE 0, GO TO 53
      LET NIN=NSOOP(KRW)
      LET I1=0
      LET I2=0
      DO TO 51, FOR J=(1)(NIN)
      LET KK=SORW(KRW,J)
      IF KK NE K, GO TO 51
      LET II=SOOP(KRW,J)
      IF II EQ 1, LET I1=1
      IF II EQ 2, LET I2=2
51    LOOP
      IF I1 EQ 0, GO TO 52
      LET TIM(K,1)=TIM(K,1)+T
52    IF I2 EQ 0, GO TO 53
      LET TIM(K,2)=TIM(K,2)+T
53    LOOP
      WRITE ON TAPE 6
      FORMAT ('1SUMMARY REPORT FOR THIS RUN'//)
      WRITE ON TAPE 6
      FORMAT (S5,'TOTAL THROUGHPUT'//
     1 S8,'RUNWAY',S8,'OPERATIONS PERFORMED'/S19,'LANDINGS  TAKEOFFS',
     2 S4,'TOTAL'/)
      LET MLAND=0
      LET MTOFF=0
      DO TO 1, FOR EACH RW K
      LET MLAND=MLAND+TNRW(K,2)
      LET MTOFF=MTOFF+TNRW(K,1)
      LET NOPS=TNRW(K,2)+TNRW(K,1)
      WRITE ON TAPE 6, K,TNRW(K,2),TNRW(K,1),NOPS
      FORMAT (S10,I1,S4,3I10)
1     LOOP
      LET NOPS=MLAND+MTOFF
      WRITE ON TAPE 6, MLAND,MTOFF,NOPS
      FORMAT (S9,'TOTAL ',3I10///)
      WRITE ON TAPE 6
      FORMAT (S5,'AVERAGE HOURLY THROUGHPUT'//
     1 S8,'RUNWAY',S8,'OPERATIONS PERFORMED'/S19,'LANDINGS  TAKEOFFS',
     2 S4,'TOTAL'/)
      LET THR=TEND-TBEG
      LET TLAND=0.
      LET TTOFF=0.
      DO TO 2, FOR EACH RW K
      LET T1=TNRW(K,1)
      LET TTOFF=TTOFF+T1
      IF TIM(K,1) GT 0.0, GO TO 7
      LET T1=0.
      GO TO 8
7     LET T1=T1/TIM(K,1)
8     LET T2=TNRW(K,2)
      LET TLAND=TLAND+T2
      IF TIM(K,2) GT 0.0, GO TO 9
```

```
      LET T2=0.
      GO TO 10
 9    LET T2=T2/TIM(K,2)
10    LET T=T1+T2
      WRITE ON TAPE 6, K,T2,T1,T
      FORMAT (S10,I1,S4,3D8.1)
 2    LOOP
      LET T=(TLAND+TTOFF)/THR
      LET TLAND=TLAND/THR
      LET TTOFF=TTOFF/THR
      WRITE ON TAPE 6, TLAND,TTOFF,T
      FORMAT (S9,'TOTAL',S1,3D8.1///)
      IF CAP LE 0, GO TO 4
      WRITE ON TAPE 6
      FORMAT (S5,'AVERAGE HOURLY DELAY'//
     1  S6,'RUNWAY',S11,'DELAY (MINUTES)'/S19,'LANDINGS  TAKEOFFS',S4,
     2  'TOTAL'/)
      LET DLAND=0.
      LET DTOFF=0.
      DO TO 3, FOR EACH RW K
      LET T1=TDRW(K,1)
      LET DTOFF=DTOFF+T1
      IF TIM(K,1) GT 0.0, GO TO 11
      LET T1=0.
      GO TO 12
11    LET T1=T1/TIM(K,1)
12    LET T2=TDRW(K,2)
      LET DLAND=DLAND+T2
      IF TIM(K,2) GT 0.0, GO TO 13
      LET T2=0.
      GO TO 14
13    LET T2=T2/TIM(K,2)
14    LET T=T1+T2
      WRITE ON TAPE 6, K,T2,T1,T
      FORMAT (S10,I1,S4,3D8.1)
 3    LOOP
      LET T=(DLAND+DTOFF)/THR
      LET DLAND=DLAND/THR
      LET DTOFF=DTOFF/THR
      WRITE ON TAPE 6, DLAND,DTOFF,T
      FORMAT (S9,'TOTAL',S1,3D8.1///)
      DO TO 6, FOR EACH H I
      DO TO 5, FOR EACH SLOT J
      LET IDT(J)=IDT(J)+NDLAY(I,J)
 5    LOOP
 6    LOOP
      CALL DOUT
 4    STOP
      END ENDS
```

```
REPORT DOUT
           930.     L.                                                                                                       R.
FOR EACH SLOT J
           931.     L.   14                                                                                                  R.
           DELAY PROFILE - NUMBER OF AIRCRAFT IN EACH DELAY CATEGORY BY HOUR
           932.     L.X                                                                                                      R.Y1
                                            MINUTES DELAYED
           933.     L.X                                                                                                      R.
  HOUR    NO DELAY  00-05  05-10  10-15  15-20  20-25  25-30  30-35  35-40  40-45  45-50  50-55  55-60  OVER 60
           934.     L.Y                                                                                                      R. 1
   **        ***     ***    ***    ***    ***    ***    ***    ***    ***    ***    ***    ***    ***     ***
           935.     L.X                                                                                                      R.
   I            14(NDLAY(I,J))
           936.     L. X                                                                                                     R.
FOR EACH J I
           937.     L. Y                                                                                                     R.
 TOTAL       ***     ***    ***    ***    ***    ***    ***    ***    ***    ***    ***    ***    ***     ***
           938.     L.X                                                                                                      R.
             14(10T(J))
           939.     L. Y                                                                                                     R.
END LEFT HALF OF DOUT                                                   END RIGHT HALF OF DOUT
           940.     L.                                                                                                       R.
```

APPENDIX F

PROCESSING THE LGA TRAFFIC INPUT DATA

In Chapter 2 of this report we discussed a run of DELCAP using traffic schedule data from [3] together with actual runway-use information from the CATER data. These two data sources were matched, and the discrepancies noted were resolved to the extent possible. Figure F.1 records those errors, inconsistencies and mismatches which were found but could not be reconciled.

Three flights identified as TWPCK were listed among those scheduled, but were rejected because their flight identification numbers had incorrect form (correct form is two alphabetic characters followed by 3 or 4 numeric characters). We were unable to discover anything further about the identity of these flights, although it is speculated that they are TWA pilot check flights.

Three flights had a discrepancy between a scheduled aircraft type and the type actually used. Two Eastern flights scheduled for heavy aircraft actually used category 3 aircraft, and one Air New England flight scheduled for a light aircraft actually used a category 3. In all three cases, the actual type used was input to the model.

A total of 43 flights were not matched. Of this total, 24 are National flights which were scheduled but did not occur because of a strike by National employees. This left unexplained a total of six scheduled flights which did not actually occur, and 13 flights which occurred but were not among the list of those scheduled, amounting altogether to an error in less than 3 percent of all the scheduled flights.

A list of all flights, arrival/departure designator, aircraft type, runway used, scheduled and actual operation time is given in Figure F.2 at the end of this appendix in order of actual operation time. All times are in Greenwich Mean Time (GMT), and since local time on October 25th was Eastern Daylight Time, one can obtain local time from GMT by subtracting 4 hours.

Several other problems in reconciling the two data sets were encountered and overcome. The schedule data, being computer output, had a fixed format: 7-character flight ID, two leading alphabetic characters, followed by a zero and 4 trailing numerics. The CATER data listed the flight ID with no extra zeroes between the alphabetic airline identifier and the numeric flight code. In addition, airline identifiers for suburban carriers are not the same in the two sources. For instance Air New England is ANE in the CATER data and NE in the schedule data, Command Airways is CMD in CATER and DD in the other, and Catskill Airways is CSK in CATER and KF in the schedule data.

FIGURE F.1

Inconsistencies in Two Data Sources

ERRORS IN SCHEDULED TRAFFIC INPUT DATA ARE STARRED

S	*TWPCK	1300	A	3
S	*TWPCK	1655	A	
S	*TWPCK	1430	D	3

AIRCRAFT TYPE INCONSISTENCY. SCHEDULED TYPE IN PARENTHESES.

EA0414	442	417	A	3(1)	22
NE1448	1335	1320	D	3(2)	13
EA0011	1422	1400	D	3(1)	13

732 SCHEDULED OPERATIONS READ OF WHICH 30 WERE NOT MATCHED
715 CATER OPERATIONS OF WHICH 13 WERE NOT MATCHED

FLIGHTS NOT FOUND

IN THE SCHEDULE DATA

NA0605	18	A	3
NA0611	100	D	1
NA0605	100	D	3
NA0612	413	A	3
NA0608	417	A	3
[illegible]0729	420	A	3
NA0608	455	D	3
[illegible]D0001	1125	A	3
NA0143	1305	D	3
NA0055	1313	A	3
NA0055	1355	D	3
NA0092	1417	A	3
NA0144	1523	A	1
NA0439	1535	D	3
AL0621	1547	A	3
NA0428	1550	A	3
NA0141	1640	D	1
NA0099	1650	D	3
NE1446	1735	D	3
NA0006	1807	A	1
AL0677	1845	D	3
NA0405	1916	A	3
NA0091	1920	D	1
NA0129	2015	D	3
NA0146	2128	A	3
NA0094	2150	A	1
NA0145	2230	D	3
CB0601	2245	D	2
NA0093	2300	D	1
NA0090	2350	A	1

IN THE CATER DATA

CB2261	24	A	2	31
CB2600	43	A	2	31
AA2350	152	D	3	31
EA0706	243	D	3	31
EA2435	355	D	3	04
EA7121	1132	D	3	13
UA0903	1206	D	3	13
EA0122	1340	D	3	13
UA7218	1437	A	3	22
TW0329	1553	D	3	13
EA7323	1716	A	3	22
NE0874	2248	A	3	22
NE2472	2354	D	3	31

Another difference between the two sets concerns the designation of the Eastern Air Shuttle flights. Each such flight appeared in the schedule data once with the symbol < as the final character in the ID. It appears in the CATER data as many times as there were sections of the flight. There were different numbering schemes in use for the shuttle flights in the two data bases, which required further hand reconciliation. All of these discrepancies were identified and standard formats decided upon, using the two-letter airline code from the schedule data and a four-digit, right-justified numeric flight code. Additional sections of the air shuttle were included as scheduled when they actually occurred. Differing shuttle numbering schemes were eliminated by an arbitrary choice of one coherent scheme. The result of these efforts is the list of 702 flights in Figure F.2.

FIGURE F.2

LGA Scheduled Flights Input to DELCAP

DETAILED FLIGHT OUTPUT

FLT ID	A/D	TYPE	RUNWAY	SCHEDULED	ACTUAL
TW0465	D	3	31	2250	0
AA0350	D	3	31	2255	1
AA0424	A	3	22	2300	1
AL0753	D	3	31	2210	2
AA0592	A	3	22	2234	3
AL0757	D	3	31	2330	4
UA0422	A	3	22	2308	5
EA0024	D	3	31	2310	6
NE1442	D	3	31	2300	8
AA0296	A	3	22	2305	8
UA0332	A	3	22	2323	10
EA1531	D	3	31	0	11
EA2522	A	3	22	12	12
AA0228	D	3	31	2330	12
TW0253	D	3	31	2340	14
TW0359	D	3	31	2345	16
DL1906	A	3	22	2350	16
PI0053	D	3	31	2330	17
UA0250	A	3	22	2350	17
AA0430	A	3	22	2347	18
TW0533	D	3	31	2355	19
EA0541	D	3	31	2255	20
AA0511	D	3	31	2245	22
AA0341	A	3	22	2300	23
AL0501	D	3	31	2345	24
EA1533	D	3	31	25	25
EA2131	D	3	31	0	26
EA1123	A	3	22	26	26
UA0922	A	3	22	2350	27
EA2132	D	3	31	27	27
TW0346	A	3	22	2330	29
NW0224	A	3	22	2351	30
EA0357	D	3	31	2350	31
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SO0719	D	3	31	[illegible]	33
UA0796	A	3	22	2347	34
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AL0749	D	3	31	0	36
NW0241	D	3	31	0	38
DL1248	A	3	22	2320	38
AA0259	D	3	31	2300	39
AL0498	A	3	22	2355	39
TW0151	D	3	31	5	40
EA2512	A	3	22	41	41
UA0424	A	3	22	2355	43
AA0447	D	3	31	2330	45
EA1125	A	3	22	46	46

UA0725	D	3	31	5	47
AA0227	D	3	31	0	48
AA0194	A	1	22	23	48
TW0166	A	3	22	2340	50
DL0200	A	3	22	2340	51
AA0284	A	3	22	2347	53
AA0545	A	3	22	0	55
AA0154	A	3	22	2350	57
EA1131	A	3	22	40	58
TW0350	A	3	22	32	100
AA0526	A	3	22	30	101
AA0401	D	3	31	0	101
AA0106	A	3	22	2013	102
EA1133	A	3	22	106	106
EA1543	D	3	31	108	108
AA0562	A	3	22	46	108
EA2141	D	3	31	100	109
EA2524	A	3	22	114	110
AA0341	D	3	31	0	110
EA0565	D	3	31	2340	111
PI0024	A	3	22	4	111
AL0451	D	3	31	45	113
EA0052	A	3	22	2355	113
DL0218	A	3	22	24	114
NC0058	A	3	22	50	116
EA0028	A	3	22	31	117
UA0387	D	3	31	55	119
AA0522	A	3	22	42	119
AA0382	A	3	22	50	120
FA1141	A	3	22	140	121
AA0251	D	3	31	20	121
AA0250	A	3	22	23	122
DL1205	D	3	31	100	123
AA0129	D	3	31	2355	124
EA2531	A	3	22	53	124
AA0430	D	3	31	30	127
EA0100	A	3	22	24	127
UA0814	A	3	22	51	129
AA0132	A	3	22	16	130
DL0200	D	3	31	20	130
TW0256	A	3	22	2340	133
EA2532	A	3	22	135	135
TW0182	A	3	22	101	136
AA0508	A	3	22	102	138
NW0230	A	3	22	103	140
AA0311	D	3	31	30	140
AA0545	D	3	31	100	142
EA0068	A	3	22	50	142
DD0047	A	2	31	2320	143
AL0547	A	3	22	50	143
TW0246	A	3	22	46	145
EA2541	A	3	22	140	146

EA0616	A	3	22	125	147
EA2142	D	3	31	142	148
AA0271	D	3	31	32	149
AA0146	A	3	22	56	150
AA0266	A	3	22	121	152
EA1541	D	3	31	100	153
EA0758	A	3	22	2352	153
EA0540	A	3	22	132	155
DU0026	D	2	22	55	156
AL0678	A	3	22	120	157
TW0476	A	3	22	127	158
BN0006	A	3	22	125	159
AL0512	A	3	22	55	201
EA0415	D	1	31	100	202
EA1143	A	3	22	202	202
TW0554	A	3	22	132	204
AA0354	A	3	22	140	206
AA0479	D	3	31	115	208
EA2542	A	3	22	202	209
PI0025	D	3	31	110	210
PI0056	A	3	22	147	211
DL0327	D	3	31	125	211
EA2151	D	3	31	200	213
TW0484	A	3	22	200	213
EA0417	D	3	31	100	215
AA0325	D	3	31	100	216
AA0550	A	3	22	214	218
DL0128	A	3	22	206	223
EA2544	A	3	31	220	224
TW0541	D	3	31	55	227
AL0541	D	3	31	155	228
AL0759	D	3	31	205	230
AL0547	D	3	31	130	234
EA1545	D	3	31	236	236
AA0134	A	3	31	229	239
DL0321	A	3	22	230	243
UA0926	A	3	22	233	245
AA0566	A	3	22	142	247
EA1151	A	3	22	241	250
EA0187	D	3	31	125	250
DL0123	D	3	04	240	256
EA0028	D	3	04	110	258
EA0421	D	3	04	210	311
AA0042	A	3	04	310	317
AL0624	A	3	04	314	327
EA0432	A	3	22	346	413
EA0414	A	3	22	417	442
EA0416	A	3	22	417	448
DL0534	A	3	22	420	452
DL0534	D	3	22	455	523

AA0042	A	3	22	310	702
EA2161	D	3	13	1100	1105
FA1401	D	3	13	1100	1107
AA0171	D	3	13	1100	1111
AA0483	D	3	13	1100	1111
DL1905	D	3	13	1105	1113
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AA0441	D	3	13	1105	1116
AA0427	D	3	13	1105	1117
EA0519	D	3	13	1110	1119
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EA0597	D	3	13	1120	1127
PI0057	D	3	13	1130	1135
AA0417	D	3	13	1130	1136
AA0567	D	3	13	1130	1138
AA0579	D	3	13	1130	1139
AA0307	A	3	22	1138	1142
EA1001	A	3	22	1140	1147
EA0060	A	3	22	1150	1149
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EA2401	A	3	22	1145	1153
UA0411	D	3	13	1140	1153
DL0002	D	2	22	1145	1155
AL0909	D	3	13	1145	1155
FA1411	D	3	13	1200	1157
NC0051	D	3	13	1150	1158
AA0428	A	1	22	1156	1159
TW0303	D	3	13	1145	1200
EA0351	D	3	13	1150	1201
AA0252	A	3	22	1152	1203
AA0125	D	3	13	1145	1203
AA0537	D	3	13	1150	1204
DL0061	A	3	22	1155	1204
EA2011	D	3	13	1200	1207
AA0410	A	3	22	1201	1209
UA0465	D	3	13	1200	1209
AL0746	A	3	22	1210	1212
EA0101	D	3	13	1200	1212
AA0269	D	3	13	1202	1214
KF0107	A	2	22	1215	1215
EA1413	D	3	13	1216	1216
TW0517	D	3	13	1200	1217
DL0505	A	3	22	1213	1217
AA0577	A	3	22	1210	1220
AA0609	D	3	13	1200	1220
AL0752	A	3	22	1207	1222
EA2012	D	3	13	1222	1222
DL0138	A	3	22	1154	1224
DL0209	A	3	22	1210	1226
NL1477	A	2	22	1215	1228

AA0432	A	3	22	1216	1230
KF0198	D	2	22	1250	1233
TW0467	D	3	13	1220	1233
TW0129	D	3	13	1220	1233
EA0562	A	3	22	1225	1236
NW0201	D	3	13	1230	1236
AA0440	A	3	22	1227	1238
DD0042	D	3	22	1230	1241
AA0519	D	3	13	1230	1241
NE1671	A	3	22	1225	1243
NE1449	A	3	22	1240	1246
EA0080	D	3	13	1240	1247
AA0275	D	3	13	1240	1249
AL0663	D	3	13	1245	1250
TW0560	A	3	22	1240	1251
NE1061	A	3	22	1230	1252
TW0456	A	3	22	1240	1254
BN0001	D	3	13	1240	1255
AL0751	D	3	13	1250	1256
EA2411	A	3	22	1253	1256
TW0315	D	3	13	1245	1257
AA0124	A	3	22	1247	1259
EA0363	D	3	13	1220	1301
TW0112	A	3	22	1233	1301
UA0947	D	3	13	1250	1302
EA1011	A	3	22	1246	1302
AL0562	A	3	22	1245	1304
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TW0127	D	3	13	1250	1307
EA1421	D	3	13	1300	1312
AA0360	A	3	22	1300	1312
DL0525	D	3	13	1255	1313
AA0434	A	3	22	1301	1314
AA0428	D	1	13	1245	1315
NE1476	D	3	22	1300	1316
AL0435	A	3	22	1245	1316
EA2021	D	3	13	1300	1317
EA1423	D	3	13	1310	1319
DL0209	D	3	13	1310	1320
UA0326	A	3	22	1300	1320
AA0432	D	3	13	1300	1321
AA0235	D	3	13	1300	1321
AA0529	D	1	13	1300	1322
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NE1072	D	3	22	1315	1325
PI0076	A	3	22	1250	1325
AA0577	D	3	13	1255	1327
AL0442	A	3	22	1255	1328
NE1062	D	3	22	1320	1328

EA0594	A	3	22	1315	1329
AA0440	D	3	13	1300	1330
AA0245	A	3	22	1315	1333
NE1446	D	3	13	1320	1335
AL0410	A	3	22	1310	1336
DL0177	D	3	13	1325	1337
AA0398	A	3	22	1310	1338
TW0306	A	3	22	1327	1340
AA0402	A	3	22	1320	1342
AA0451	D	3	13	1325	1342
FA0741	D	3	13	1330	1344
EA0352	A	3	22	1334	1346
AL0745	D	3	13	1330	1346
EA2422	A	3	22	1347	1347
EA0563	D	3	13	1340	1349
TW0073	D	3	13	1340	1350
TW0406	A	3	22	1341	1350
AA0384	A	3	22	1343	1351
AL0435	D	3	13	1325	1354
EA2421	A	3	22	1351	1355
EA1021	A	3	22	1350	1357
TW0420	A	3	22	1352	1359
DL0608	A	3	22	1315	1401
AA0363	D	3	13	1345	1402
TW0319	D	3	13	1345	1403
FA1431	D	3	13	1400	1405
UA0990	A	3	22	1345	1407
AA0594	A	3	22	1347	1408
AL0442	D	3	13	1335	1409
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AA0229	D	3	13	1400	1411
AA0564	A	3	22	1405	1412
TW0191	D	3	13	1345	1414
FA2031	D	3	13	1400	1415
DL1995	A	3	22	1400	1415
EA1023	A	3	22	1417	1417
AA0245	D	3	13	1400	1417
AL0495	D	3	13	1345	1419
SO0710	A	3	22	1400	1421
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EA1433	D	3	13	1424	1424
AA0303	D	3	13	1400	1426
PI0077	D	3	13	1345	1427
TW0095	D	3	13	1355	1432
NW0202	A	3	22	1424	1433
DL0608	D	3	13	1355	1433
TW0310	A	3	22	1427	1434
EA1033	A	3	22	1441	1441
EA0153	D	3	13	1435	1442
PI0004	A	3	22	1350	1444

AA0523	D	3	13	1430	1444
AA0442	A	3	22	1430	1446
TW0570	A	3	22	1445	1448
EA1031	A	3	22	1443	1450
EA0892	A	3	22	1424	1452
AA0272	A	3	22	1443	1453
EA0543	D	3	13	1445	1453
NC0050	A	3	22	1450	1455
AA0389	D	3	13	1430	1455
NW0200	A	3	22	1440	1456
TW0072	A	3	22	1450	1458
TW0323	D	3	13	1445	1458
AA0412	A	3	22	1443	1459
EA2431	A	3	22	1450	1502
SO0713	D	3	13	1455	1503
EA0150	A	3	22	1451	1504
EA1441	D	3	13	1500	1505
UA0340	A	3	22	1455	1506
UA0911	D	3	13	1500	1508
PI0072	A	3	22	1447	1508
UA0469	D	3	13	1505	1510
AA0298	A	3	22	1505	1510
AL0492	A	3	22	1455	1513
TW0115	D	3	13	1500	1515
UA0450	A	3	22	1517	1516
AA0257	D	3	13	1500	1516
AA0413	D	3	13	1500	1517
AA0433	D	3	13	1500	1518
EA2041	D	3	13	1500	1519
AA0221	A	3	22	1510	1521
DL1904	D	3	13	1520	1523
TW0314	A	3	22	1529	1526
AA0142	A	3	22	1505	1529
DL0709	A	3	22	1522	1530
AA0606	A	3	22	1522	1535
AA0442	D	3	13	1530	1536
AA0463	D	3	13	1530	1538
EA2040	D	3	13	1540	1540
PI0001	D	3	13	1445	1541
EA1041	A	3	22	1540	1542
EA0163	A	3	22	1533	1545
UA0904	A	3	22	1535	1547
EA0150	D	3	13	1530	1548
AA0233	D	3	13	1540	1548
TW0124	A	3	22	1546	1552
OZ0906	A	3	22	1545	1553
AL0493	D	3	13	1545	1554
NW0207	D	3	13	1540	1556
EA1043	A	3	22	1557	1557
NW0215	D	3	13	1550	1557
AA0302	A	3	22	1548	1601
AA0273	A	3	22	1601	1602
AA0239	D	3	13	1600	1602
AA0504	A	3	22	1545	1604

EA2441	A	3	22	1550	1605
NC0053	D	3	13	1600	1606
EA0700	A	3	22	1550	1608
EA0030	A	3	22	1550	1610
EA2051	D	3	13	1600	1610
EA1451	D	3	13	1600	1611
EA0017	D	3	13	1600	1613
UA0619	D	3	13	1600	1615
AA0085	A	3	22	1600	1616
AA0221	D	3	13	1600	1617
AA0599	D	3	13	1600	1618
Tw0171	D	3	13	1605	1620
AA0524	A	1	22	1621	1621
DL0709	D	3	13	1610	1622
PI0079	D	3	13	1555	1623
DL0458	A	3	22	1603	1624
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DL0370	A	3	22	1600	1635
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AA0379	D	3	13	1630	1640
Tw0318	A	3	22	1626	1641
BN0002	A	3	22	1623	1643
EA1051	A	3	22	1640	1646
NE1447	A	3	22	1635	1648
UA0429	D	3	13	1640	1650
OZ0909	D	3	13	1645	1651
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EA0050	A	3	22	1650	1657
Tw0515	D	3	13	1645	1658
FA0115	A	3	22	1702	1659
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AA0085	D	3	13	1647	1702
AA0092	A	3	22	1654	1708
FA2061	D	3	13	1700	1708
DL0458	D	3	13	1700	1710
AA0370	A	3	22	1702	1711
FA2452	A	3	22	1713	1713
FA1461	D	3	13	1700	1714
TW0333	D	3	13	1645	1715
AA0119	D	3	13	1700	1717
Tw0161	D	3	13	1700	1718
Tw0292	A	3	22	1710	1718
AL0936	A	3	22	1653	1720

EA2062	D	3	13	1722	1722
EA1463	D	3	13	1723	1723
EA0545	D	3	13	1659	1724
DL0367	D	3	13	1710	1725
UA0918	A	3	22	1721	1725
TW0322	A	3	22	1726	1728
EA0151	D	3	13	1705	1729
EA0219	D	3	13	1720	1731
DL0465	A	3	22	1731	1734
AA0572	A	3	22	1647	1736
NE1663	A	3	22	1710	1737
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AA0082	D	3	13	1730	1745
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AA0574	A	3	22	1741	1748
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UA0917	D	3	13	1745	1752
AA0373	D	3	13	1745	1754
AA0467	D	3	13	1730	1756
AL0857	D	3	13	1745	1757
AA0446	A	3	22	1739	1757
AA0395	A	3	22	1746	1758
TW0337	D	3	13	1745	1759
TW0512	A	3	22	1742	1800
EA0115	D	3	13	1750	1800
TW0436	A	3	22	1754	1802
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TW0125	D	3	13	1755	1808
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NE1664	D	3	13	1759	1811
DL0212	A	3	22	1746	1811
EA0021	D	3	13	1807	1813
AL0828	A	3	22	1749	1813
EA0574	A	3	22	1802	1818
AA0633	D	3	13	1800	1818
BN0009	D	3	13	1800	1819
NE1674	D	3	13	1815	1820
AA0249	A	3	22	1800	1820
EA1063	A	3	22	1822	1822
AA0355	D	3	13	1800	1823
UA0826	A	3	22	1811	1825

EA2072	D	3	13	1825	1825
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EA1473	D	3	13	1828	1828
EA1475	D	3	13	1830	1832
AA0431	A	3	22	1820	1835
AA0617	D	3	13	1830	1837
TW0376	A	3	22	1826	1839
EA2471	A	3	22	1846	1842
NC0052	A	3	22	1840	1843
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AA0335	D	3	13	1830	1847
EA0016	A	3	22	1825	1847
DL0457	D	3	13	1840	1849
UA0378	A	3	22	1847	1850
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AA0482	A	3	22	1843	1853
AL0935	D	3	13	1835	1853
AL0758	A	3	22	1747	1855
UA0910	A	3	22	1843	1856
EA0574	D	3	13	1840	1858
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UA0674	A	3	22	1846	1859
EA1481	D	3	13	1900	1900
EA2081	D	3	13	1900	1901
AA0454	A	3	22	1845	1901
TW0086	A	3	22	1846	1903
TW0339	D	3	13	1845	1906
EA1073	A	3	22	1906	1906
AA0364	A	3	22	1812	1908
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AA0208	A	3	22	1845	1916
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EA2082	D	3	31	1923	1923
AL0502	A	3	22	1855	1924
TW0553	D	3	31	1900	1925
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DL0223	D	3	31	1910	1927
NW0222	A	3	22	1915	1928
AA0301	D	3	31	1915	1929
AA0326	A	3	22	1914	1930
EA2084	D	3	31	1931	1931
TW0330	A	3	22	1926	1933
AL0747	D	3	31	1630	1934
EA2491	A	3	22	1940	1934
BU0094	A	3	22	1920	1937

TW0255	D	3	31	1900	1938
AA0432	D	3	31	1930	1942
AA0558	A	3	22	1935	1944
EA1081	A	3	22	1938	1946
AA0394	A	3	22	1940	1952
AA0426	A	3	22	1943	1953
EA1493	D	3	31	1953	1953
TW0475	D	3	31	1935	1955
EA2432	A	3	22	1955	1955
AA0541	D	3	31	1935	1957
AA0455	D	3	31	1930	1958
NE1445	A	3	22	1940	2000
NC0055	D	3	31	1940	2001
EA0748	A	3	22	1950	2003
EA2091	D	3	31	2000	2006
TW0170	A	3	22	1955	2007
AL0509	D	3	31	1945	2008
DL1967	A	3	22	1950	2010
TW0343	D	3	31	1945	2012
PI0030	A	3	22	1940	2012
UA0303	D	3	31	1955	2013
EA1491	D	3	31	2000	2015
AA0925	A	3	22	2000	2015
EA0162	D	3	31	1955	2016
EA1035	A	3	22	2017	2017
UA0921	D	3	31	2000	2018
UA0415	D	3	31	2000	2020
EA2092	D	3	31	2020	2024
AA0538	A	3	22	2016	2025
EA0365	D	3	31	2005	2026
TW0147	D	3	31	1950	2027
EA1495	D	3	31	2020	2029
EA1043	A	3	22	2030	2030
AA0305	D	3	31	2000	2031
AA0175	D	3	31	2005	2032
EA1091	A	3	22	2040	2032
AA0326	D	3	31	1950	2033
EA0898	A	3	22	2016	2035
EA0547	A	3	22	2025	2036
NW0235	D	3	31	2015	2038
UA0763	D	3	31	2010	2039
TW0334	A	3	22	2026	2041
TW0144	A	3	22	1950	2043
UA0650	A	3	22	2030	2045
EA2491	A	3	22	2050	2047
EA0577	D	3	31	2015	2049
NE1444	D	3	31	2030	2053
AA0261	A	3	22	2045	2055
UA0351	D	3	31	2030	2057
AA0436	A	3	22	2047	2057

EA0020	A	3	22	2025	2058
EA1503	D	3	31	2100	2100
NC0054	A	3	22	2040	2100
AA0375	D	3	31	2030	2106
AA0426	D	3	31	2030	2107
KF0116	A	2	22	2045	2107
FA1093	A	3	22	2100	2109
DL1996	D	3	31	2040	2109
DL0565	D	3	31	2040	2111
EA2402	A	3	22	2111	2111
EA2101	D	3	31	2100	2112
AA0488	A	3	22	2031	2112
SO0321	A	3	2	2030	2114
AA0419	D	3	31	2045	2116
DL0120	A	3	22	2040	2116
TW0347	D	3	31	2045	2118
UA0544	A	3	22	2101	2118
EA2494	A	3	22	2110	2119
TW0286	A	3	22	2104	2122
AA0549	D	3	31	2055	2123
PI0033	D	3	31	2100	2125
AL0506	A	3	22	2040	2125
BN0005	D	3	31	2100	2127
AA0075	D	3	31	2055	2128
EA0053	D	3	31	2105	2129
DL0021	A	2	22	2025	2129
EA0544	A	3	22	2040	2131
EA1501	D	3	31	2100	2132
AA0348	A	1	22	2053	2133
TW0251	D	3	31	2050	2135
AA0391	D	3	31	2100	2136
NW0228	A	3	22	2120	2136
TW0572	A	3	22	2040	2139
UA0914	A	3	22	2110	2142
TW0163	D	3	31	2100	2142
KF0117	D	2	31	2120	2143
AL0874	A	3	22	2053	2143
FA2501	A	3	22	2150	2145
AL0760	A	3	22	2122	2147
EA2102	D	3	31	2140	2148
EA1101	A	3	22	2143	2149
EA0547	D	3	31	2115	2150
AA0473	A	3	22	2111	2150
DL0221	D	3	31	2120	2152
EA2104	D	3	31	2153	2153
EA1103	A	3	22	2153	2153
DL0426	A	3	22	2123	2155
EA0397	D	3	31	2130	2156
PI0074	A	3	22	2112	2157
NE1441	A	3	22	2110	2202

AA0436	D	3	31	2130	2205
AA0460	A	3	22	2117	2205
EA0759	A	3	22	2140	2206
UA0368	A	3	22	2152	2208
AA0261	D	3	31	2125	2209
TW0338	A	3	22	2130	2210
UA0969	D	3	31	2127	2211
AA0270	A	3	22	2145	2212
AA0530	A	1	22	2147	2213
TW0285	D	3	31	2130	2214
DD0946	D	2	31	2055	2214
TW0056	A	3	22	2151	2216
EA2502	A	3	22	2217	2217
NE1665	A	3	22	2140	2219
EA1513	D	3	31	2220	2220
AA0098	A	3	22	1940	2221
AL0747	A	3	22	1950	2225
EA2111	D	3	31	2200	2226
NC0057	D	3	31	2155	2230
UA0712	A	3	22	2200	2230
EA2504	A	3	22	2232	2232
AL0506	D	3	31	2130	2232
SO0717	D	3	31	2110	2234
DL0121	D	3	31	2140	2236
AA0420	A	3	22	2147	2236
UA0557	D	3	31	2200	2237
EA1105	A	3	22	2237	2237
EA0362	A	3	22	2217	2239
EA1511	D	3	31	2200	2240
DL0609	A	3	22	2203	2241
EA2112	D	3	31	2242	2242
TW0456	A	3	22	2147	2243
AL0679	D	3	31	2200	2244
TW0351	D	3	31	2145	2245
EA0364	A	3	22	2202	2245
TW0342	A	3	22	2230	2246
EA0029	D	3	31	2200	2247
EA1515	D	3	31	2247	2247
AL0387	D	3	31	2145	2249
AA0350	A	3	22	2217	2250
AA0473	D	3	31	2140	2251
EA1111	A	3	22	2250	2252
OZ0970	A	3	22	2137	2254
EA0024	A	3	22	2225	2255
UA0665	D	3	31	2220	2256
AA0299	A	3	22	2222	2258
TW0411	D	3	31	2155	2259
NW0233	D	3	31	2220	2300
TW0538	A	3	22	2231	2300
TW0576	A	3	22	2247	2302

AA0437	D	1	31	2200	2305
AL0738	A	3	22	2239	2306
NE1667	A	3	22	2140	2307
NE1472	D	3	31	2145	2308
PI0052	A	3	22	2226	2308
DL0723	D	3	31	2225	2310
EA2511	A	3	22	2253	2311
PI0049	D	3	31	2220	2311
TW0495	D	3	31	2225	2313
AL0677	A	3	22	2035	2314
NE1443	A	3	22	2210	2315
AA0421	D	3	31	2130	2315
NE1668	D	3	31	2215	2316
AA0288	A	3	22	2247	2317
CB0609	A	2	22	2210	2318
EA0759	D	3	31	2230	2319
EA0564	A	3	22	2156	2320
AA0035	D	3	31	2155	2321
FA2514	A	3	22	2322	2322
EA0544	D	3	31	2145	2323
FA1127	A	3	22	2324	2324
EA2121	D	3	31	2300	2325
EA1523	D	3	31	2327	2327
AA0228	A	3	22	2240	2327
UA0929	D	3	31	2300	2329
EA1521	D	3	31	2300	2329
TW0355	D	3	31	2245	2331
AL0737	D	3	31	1950	2333
TW0464	A	3	22	2255	2333
DL0402	D	3	31	2300	2335
NW0242	A	3	22	2250	2335
AL0496	A	3	22	2255	2337
AA0595	D	3	31	2130	2338
EA2122	D	3	31	2330	2339
EA0357	A	3	22	2305	2341
AA0531	D	1	31	2250	2344
EA1525	D	3	31	2346	2346
AA0166	A	3	22	2247	2346
EA1121	A	3	22	2345	2347
AA0139	D	3	31	2230	2348
UA0635	D	3	31	2315	2349
TW0041	D	3	31	2300	2351
SO0716	A	3	22	2320	2351
EA2124	D	3	31	2350	2352
NE1678	D	3	22	2225	2353
EA0595	D	3	31	2320	2353
EA0358	A	1	22	2330	2354
OZ0971	D	3	31	2245	2355
EA2521	A	3	22	2350	2356
AA0299	D	3	31	2250	2357
AL0748	A	3	22	2300	2359

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